Minimal Mars Architecture
Lunar Testing…and then Mars

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Purpose of Minimal Architecture

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Minimal Architecture

- To show a plausibly affordable timeline for landing explorers on Mars in the 2030s
  - We will show two new affordable scenarios
- To show that crewed missions to Mars could be conducted with a limited number of new developments
- To show that a sustainable approach to Mars exploration could be initiated without exotic new technologies or extraterrestrial resources

Short-Stay Mars Orbit Concept

1 month orbital stay; Crew of 4; 4 SLS launches

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Mars

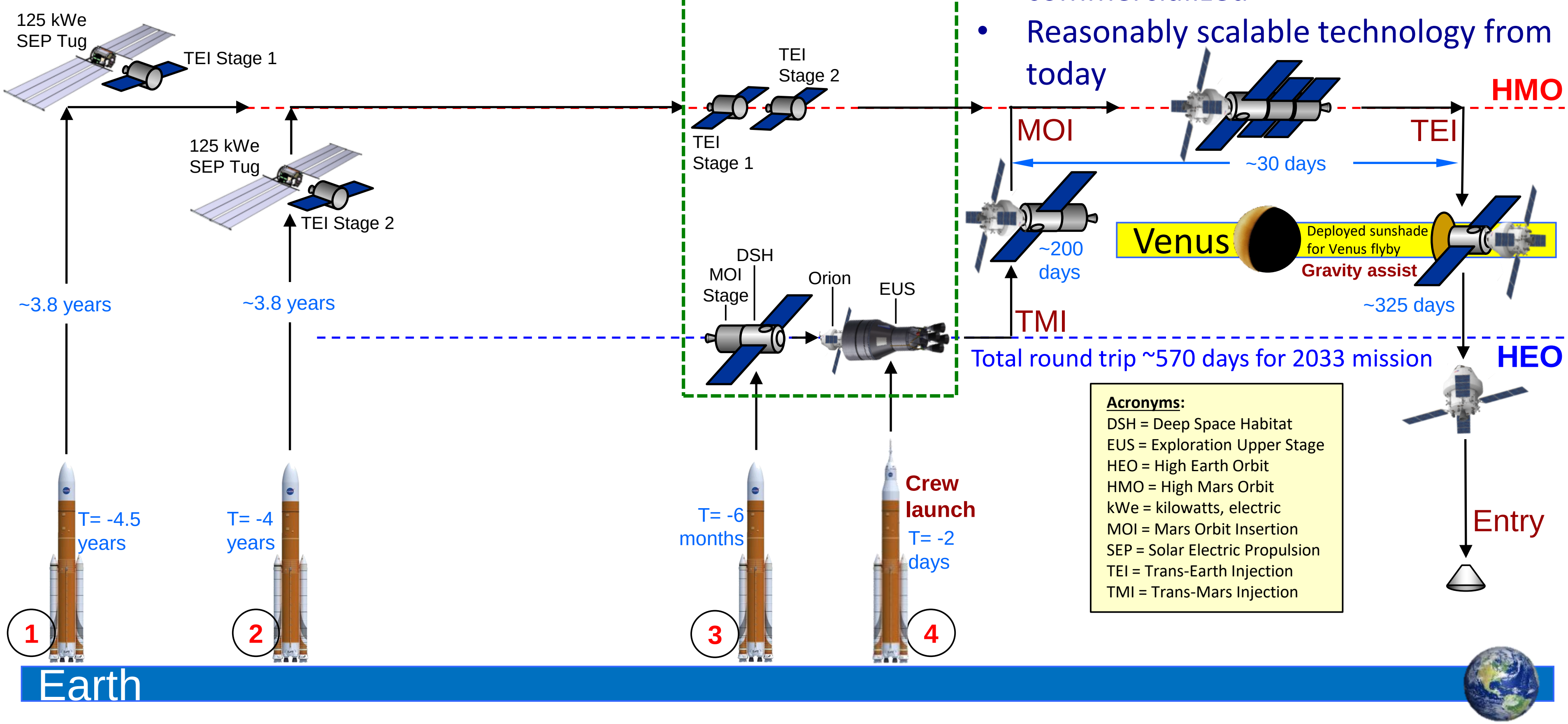
Complete set of mission elements

More affordable due to:

- 1 hab instead of 2, enabled by shorter mission
- International contribution of propulsion stages

Split architecture features:

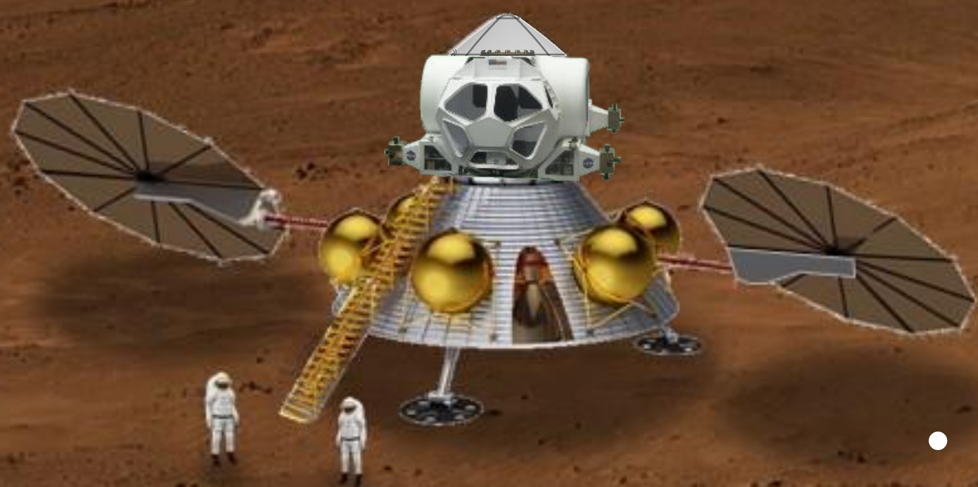
- Separation of crew & cargo
- Cargo could potentially be commercialized
- Reasonably scalable technology from today



Acronyms:
DSH = Deep Space Habitat
EUS = Exploration Upper Stage
HEO = High Earth Orbit
HMO = High Mars Orbit
kWe = kilowatts, electric
MOI = Mars Orbit Insertion
SEP = Solar Electric Propulsion
TEI = Trans-Earth Injection
TMI = Trans-Mars Injection

Mars Short Surface Stay Mission

First Crew on Mars



- Would include a separate cargo lander with pressurized rover, extra consumables, and significant science equipment
- Would be the pathfinder for a continuing series of long-stay missions starting four years later
- Could begin building

Short-Stay Mars Landing Concept

1 month surface stay; Crew of 4 to surface; 8 SLS launches

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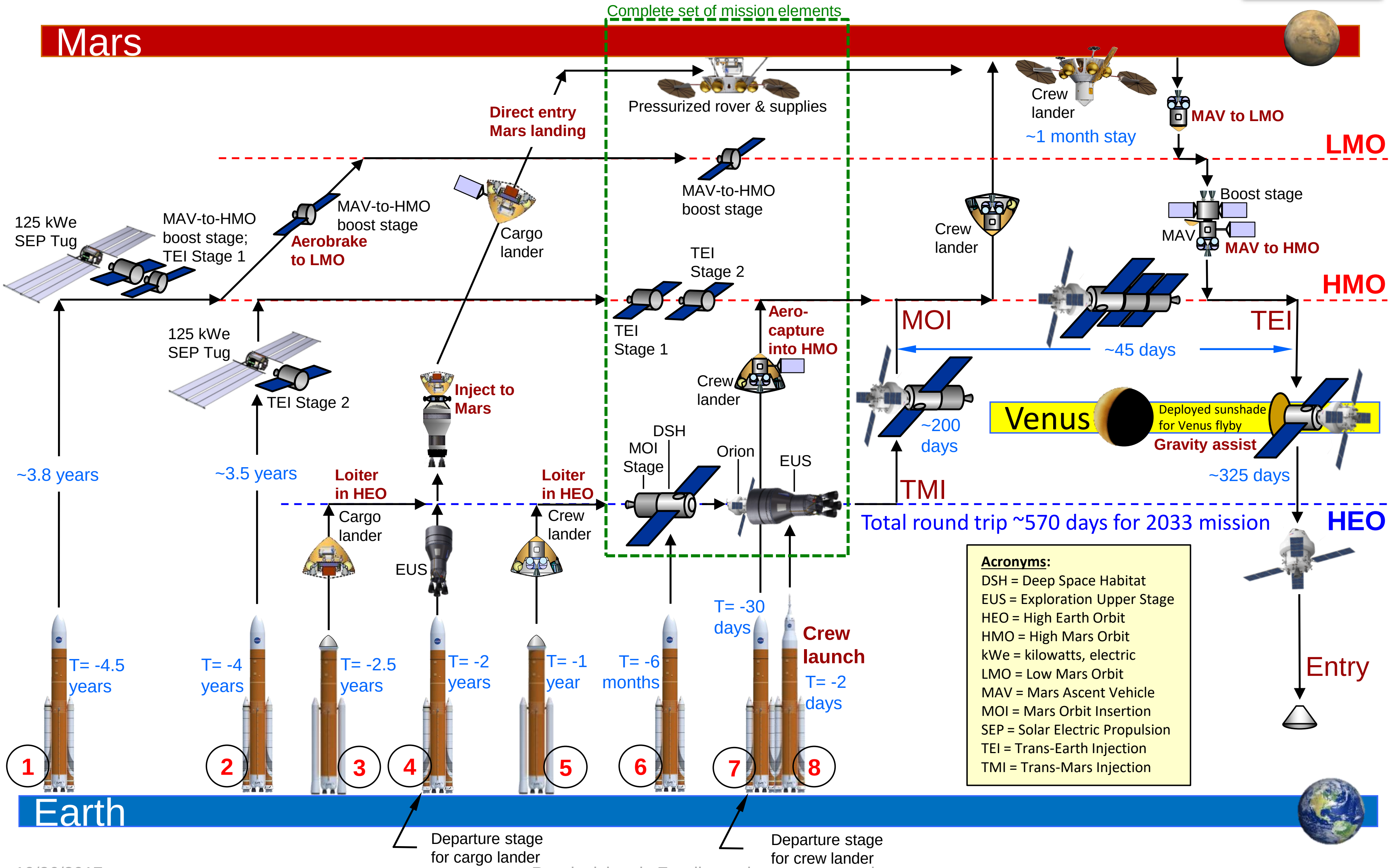

Guiding Principles for this Example of a Minimal Architecture

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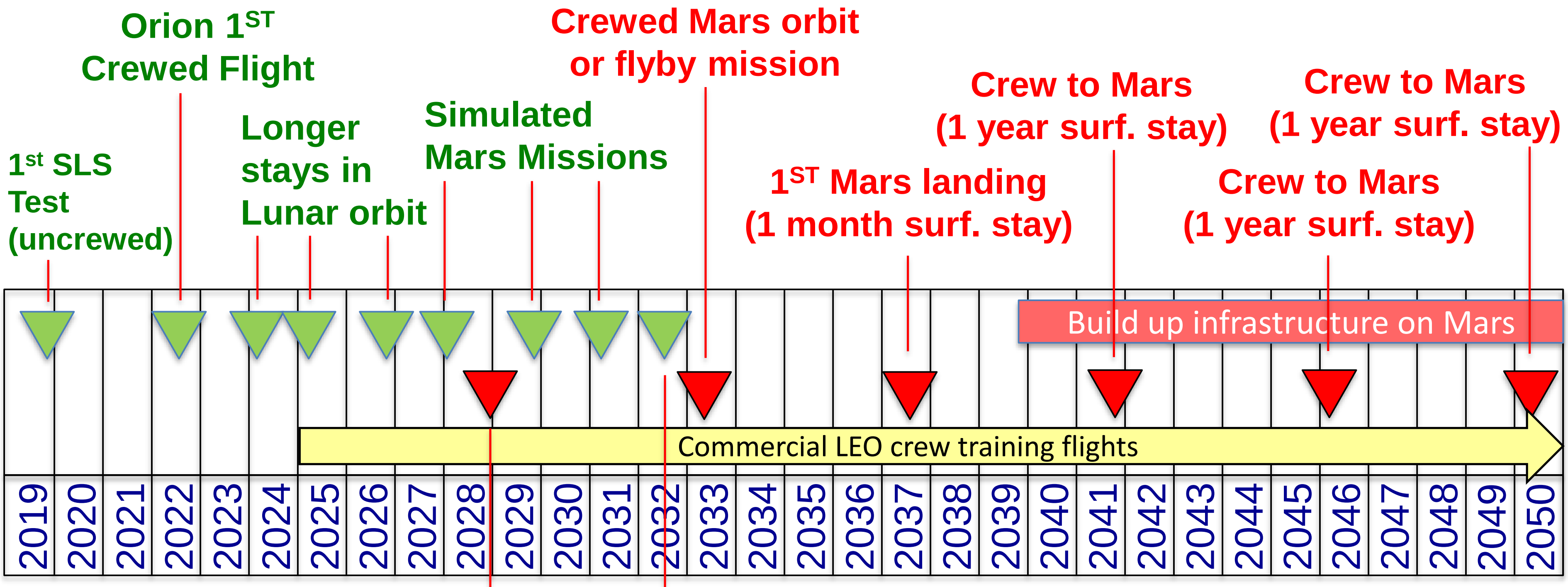
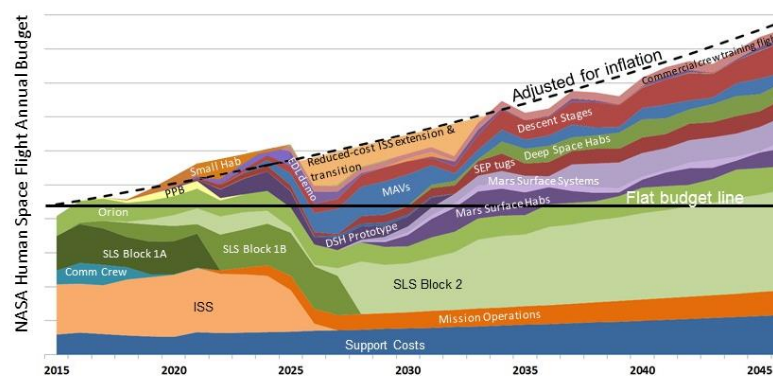
- Minimize development risk and mission risk by using proven and available technology. Minimize new vehicle development.
  - Each additional vehicle and new technology would add cost, schedule, and development risk
- Crew safety is the highest priority (e.g. provide lander abort-to-orbit)
- Humans to Mars at earliest date practical (reduces total cost)
- On-ramp higher risk and less mature technologies when affordable
  - Would not require Lunar or Mars propellant production for the first missions
  - Would not require very high power Solar Electric Propulsion (>125 kWe)
  - Delay having re-usable vehicles and refueling infrastructure for first missions
    - Re-usability would require more complex vehicles and more upfront expense
    - Designs may need to evolve for the first few missions to address flaws
    - Re-use would still require launches for cargo and fuel (and non-reusable tanker vehicles)
- It is a "minimal" but not a "minimum" architecture
  - Would not skimp on science and exploration objectives and capabilities

Notional Timeline for an Example of a 2037 Landing: Orbital mission 2033, landing 2037





Notional Timeline for an Example of a 2033 Landing

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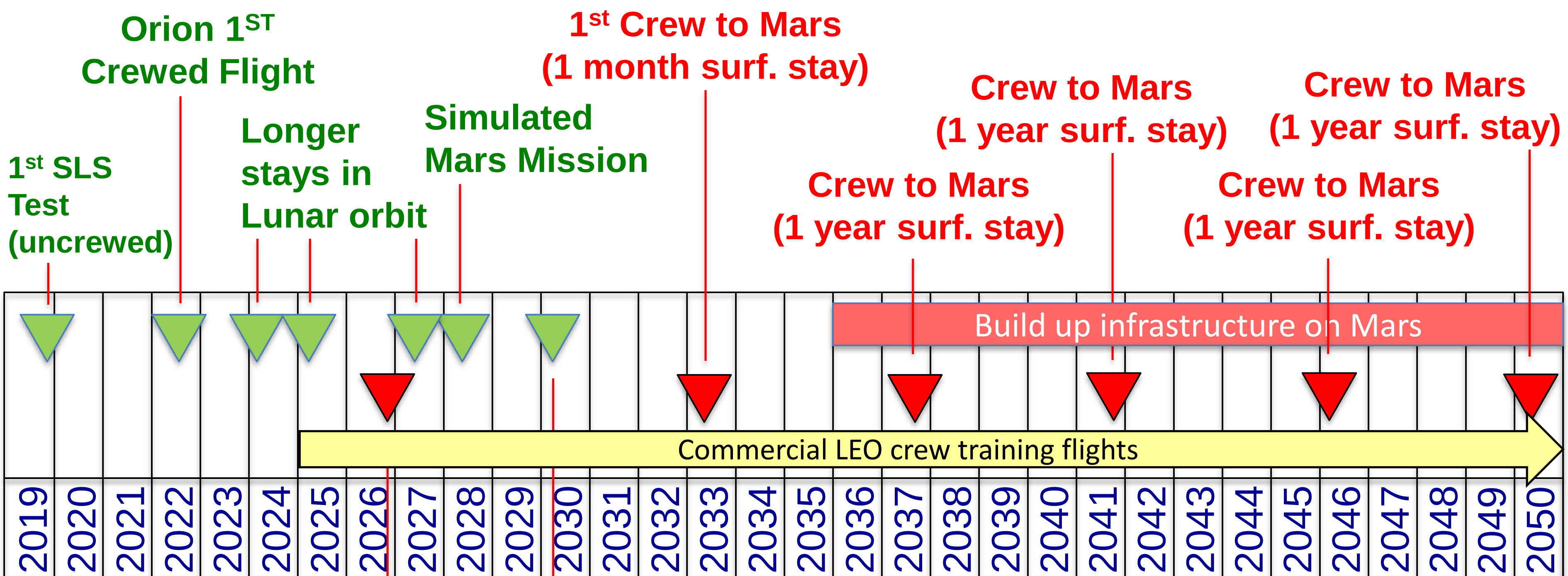

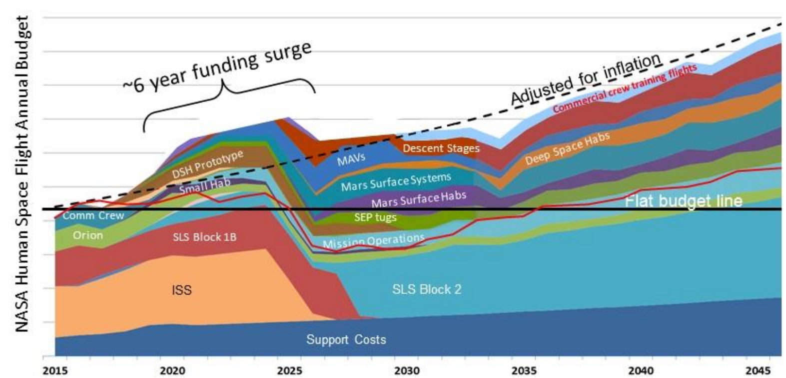

Crewed Test of Mars Lander on the Moon

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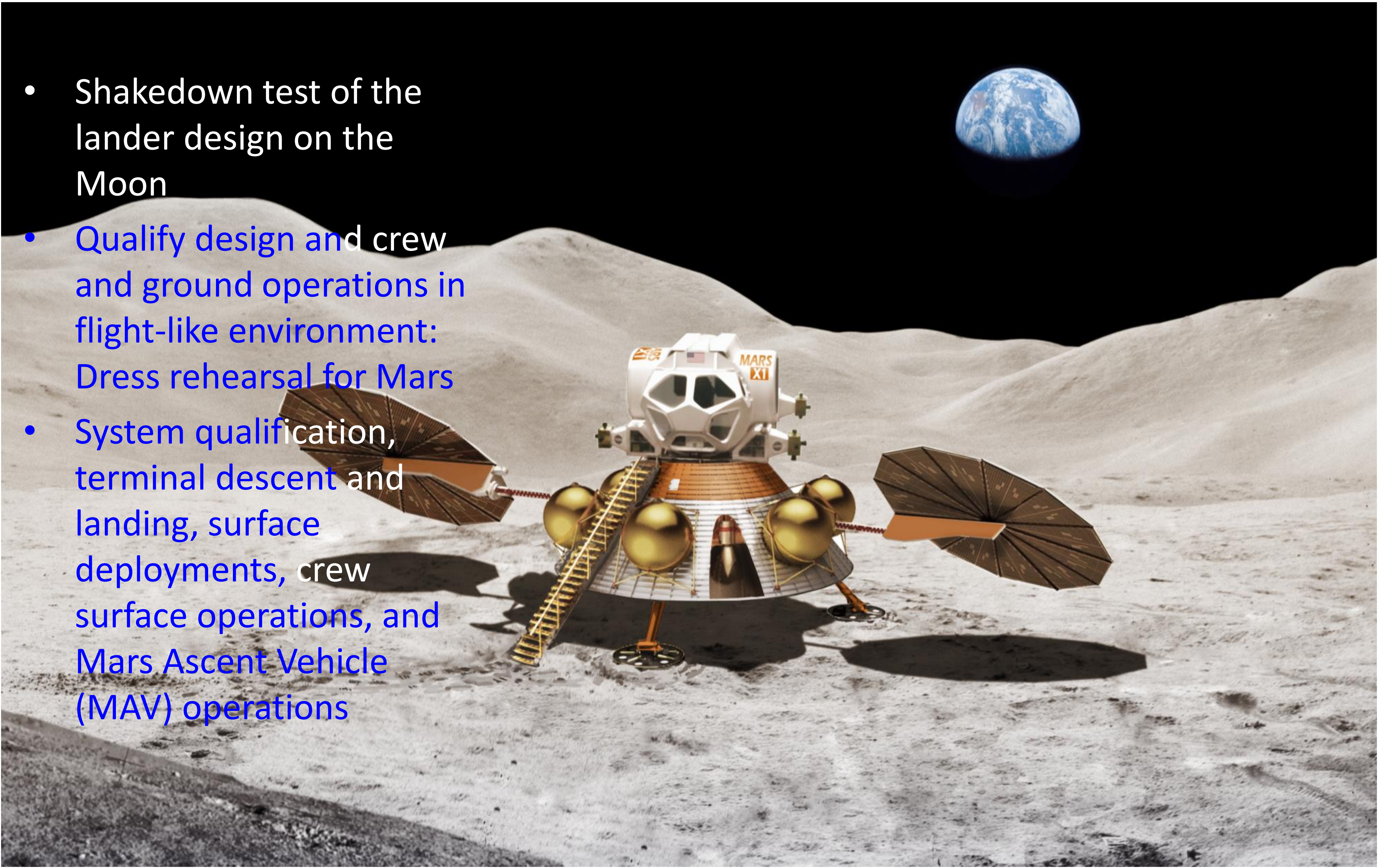
- Shakedown test of the lander design on the Moon
- Qualify design and crew and ground operations in flight-like environment: Dress rehearsal for Mars
- System qualification, terminal descent and landing, surface deployments, crew surface operations, and Mars Ascent Vehicle (MAV) operations



Six Vehicles to Enable Crewed Missions to Mars

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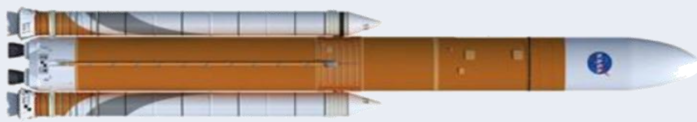
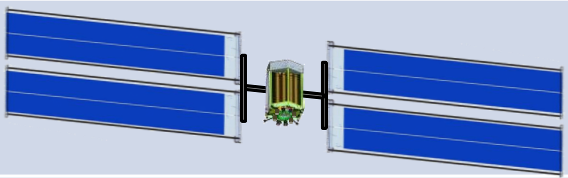
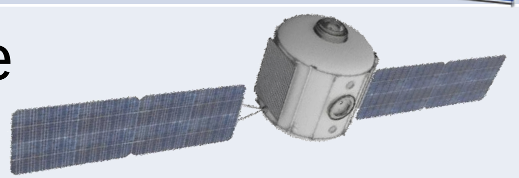
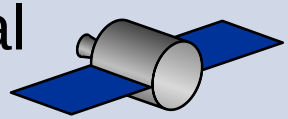
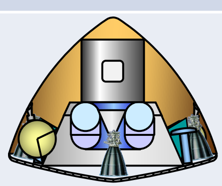
Vehicles	# Vehicles per Mission	Produc-tion Rate	
Orion 	1	1 every 4 years	In development
SLS 	8	2 per year	In development
SEP Tug ~125 kWe 	2	1 every 2 years	Studies are on contract
Deep Space Habitat 	1 (or 2 for long stay)	1 every 2 years	Studies are on contract
In-Space Chemical Propulsion Stage 	4 (or 3 for long stay)	1 per year	Could be an international contribution
Mars Lander (One crew and one cargo) 	2	1 every 2 years	Development would need to start

How Can We Make Mars Affordable?

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1. **Implement the program in phased mission campaigns**
   - **First Campaign**: Testing at the Moon with the Deep Space Gateway
     - Would perform testing in Lunar orbit and a crewed landing on the Moon to qualify the Mars vehicle designs
   - **Second Campaign**: Mars orbit mission
   - **Third Campaign**: Mars landing missions (short-stay, then long-stay)
   - **Continuing Missions**: Evolve toward a permanent presence
     - Each mission would build on the infrastructure from the previous mission
     - Would on-ramp new technologies (e.g. ISRU, food production) over time
     - Could develop a Mars base analogous to Antarctica South Pole Station
2. **Minimal Architecture**
   - Would use vehicles now under development (SLS, Orion, DSH, SEP) and minimize development of additional vehicles
3. **Engage commercial space and international partners**
   - Could use commercial crew to low Earth orbit for crew training
   - Could use commercial vehicles to provide Deep Space Gateway resupply
   - Invite international partners to provide some key elements
   - Could use commercial vehicles to deliver cargo to Mars orbit and surface as they become capable (incl. commercial SEP tugs)

Supplemental Material

Key Characteristics of Minimal Architecture

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End State	Regularly crewed international research base analogous to the Antarctic South Pole Station
Rationale	Could be sustainable on NASA's current budget adjusted for inflation Could perform the extended science investigations needed to find evidence of past life Could provide a testbed for biology in 1/3 g, food production, ISRU, etc. Could perform the extensive exploration required to develop a business case for expansion
Goals that Frame the Architecture	Crew safety, affordability, schedule timeliness, science capability
Affordability	2032 moon landing, 2033 Mars orbit, and 2037 Mars landing within inflation-adjusted budget
Possible Descope Options	Lander test in LEO rather than lunar landing Testing DSH in LEO with commercial crew rather than at DSG Descope Mars orbit mission to flyby Descope cargo lander with pressurized rover from first short-stay landing mission Descope crew size from 4 to 3 and/or landing crew size from 4 to 3 or 2
Resilience to Failure	MAV abort to orbit, backup TEI stage, possible backup MAV boost stage and DSH, Orion lifeboat
Human Landing by 2033	Could be possible with ~$3 B funding surge from 2020-2025 (mainly for concurrent ISS funding)
International Partners	New cost estimates assume IP-provided biprop in-space propulsion stages New cost estimates assume some IP-provided DSG elements (node, airlock) Potential to provide lunar landers for Deep Space Gateway Potential to provide significant Mars surface systems, e.g. power, science, ISRU
Commercial Partners	New cost estimates assume commercial LEO crew training in repurposed returned DSHs Opportunities for cargo deliveries to Deep Space Gateway Potential to provide privately-funded lunar landers for Deep Space Gateway Opportunities to provide supplies and logistics to Martian surface

Key Technologies for Minimal Architecture

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Technologies needed:	Need Date
900 day ECLSS	2027
125 kWe SEP	2028
Supersonic Retro-Propulsion	2028
Aerobraking with traditional heatshields (dual-use optional)	2035
Technologies deferred to later:	
ISRU	TBD
Cryogenic propellants	TBD
Very high power SEP (>150 kWe)	TBD
In-space refueling	TBD
Deployable EDL heatshields	TBD

Summary

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- The Minimal Architecture is an example concept for a low risk, plausibly affordable approach that could be implemented in the very near term with mostly existing technologies
- It would use vehicles currently in development or under industry study contracts, with the addition of a Mars lander and a straightforward biprop in-space propulsion stage
- It would utilize the Deep Space Gateway (DSG) for testing and a return to the Moon's surface with a crewed test of the Mars lander design
- The DSG could support other lunar landers provided by international partners and/or commercial enterprises
- In this example, the first Mars landing could be as soon as 2037 without significant NASA funding increases, or as soon as 2033 with a temporary surge in NASA funding in the early 2020s

Notional SLS Flight Scenario

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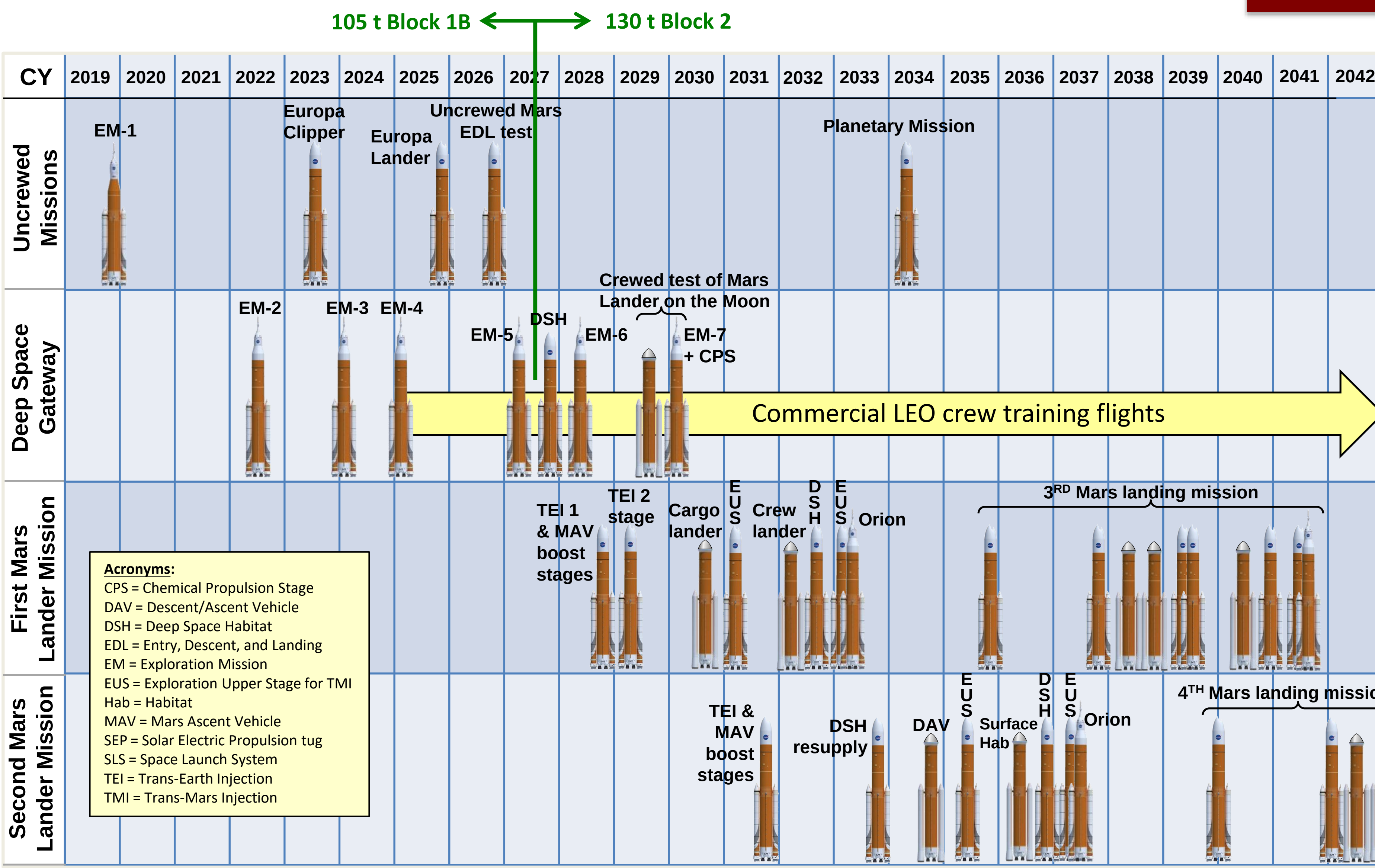

Crew Lander Concept

Could support crew of 4 for 1 week by itself, or longer with other surface assets

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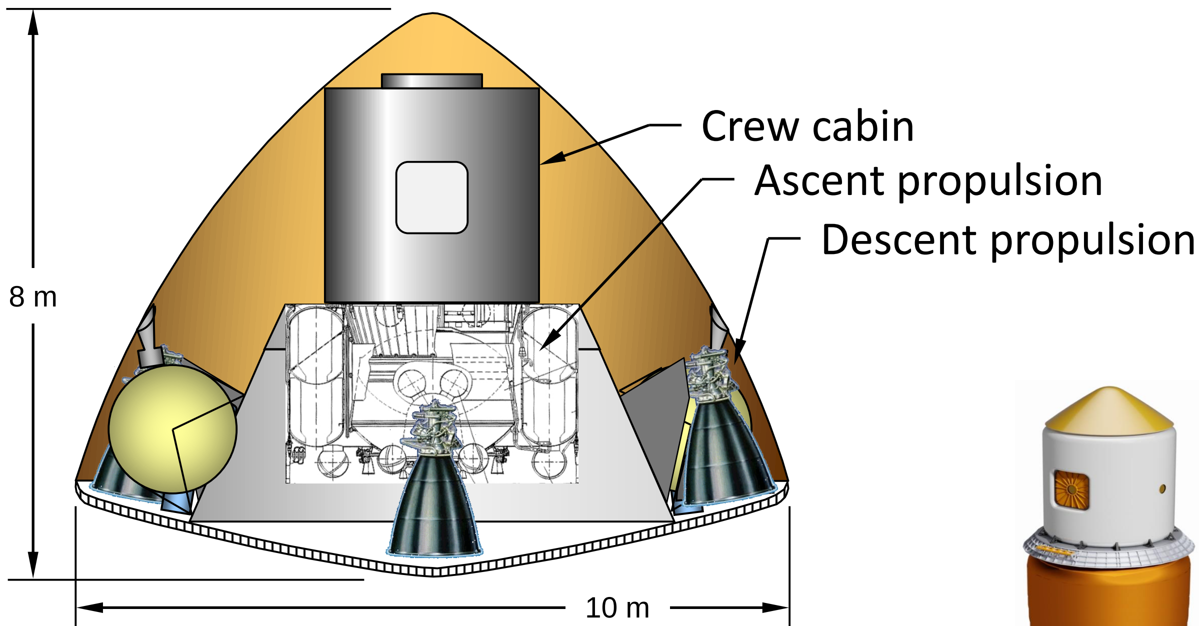
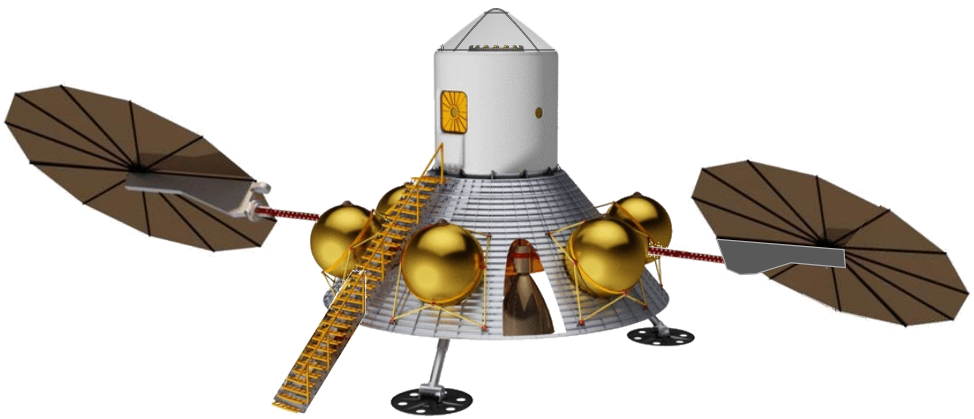
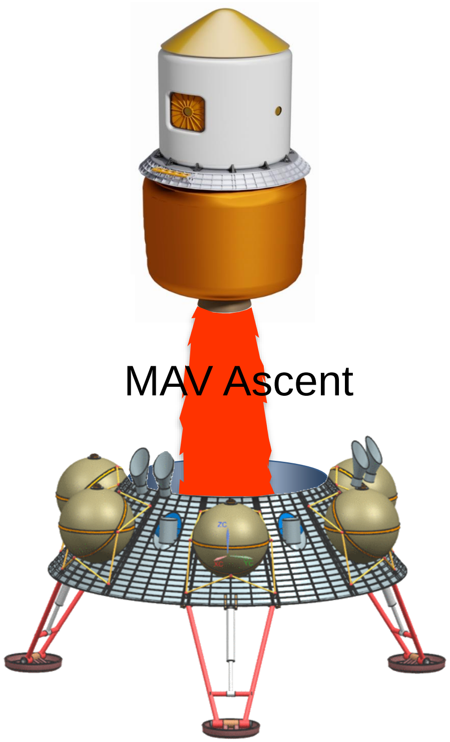
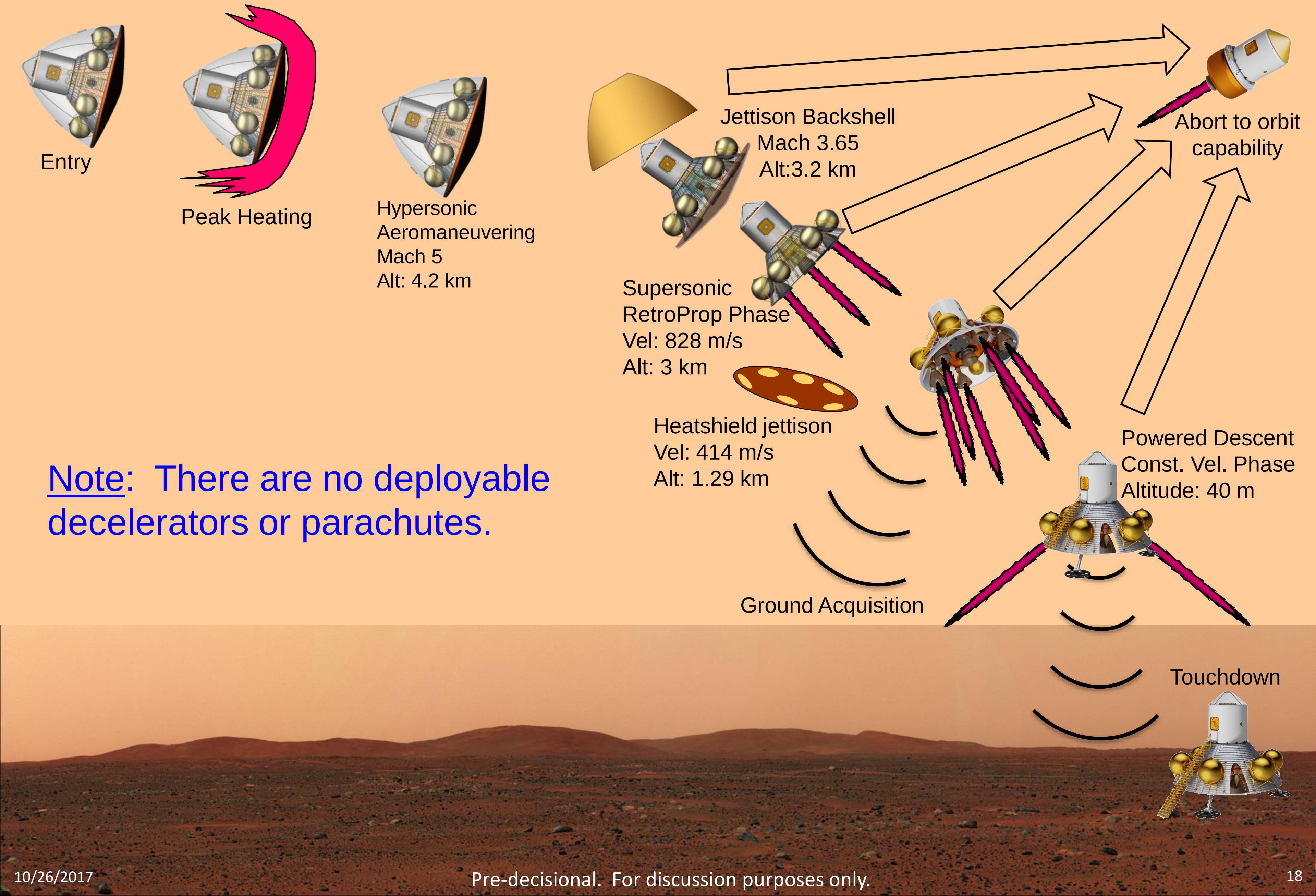
Launch




Landed Configuration



Entry, Descent, and Landing (EDL) Concept for Crewed Mars Lander



Note: There are no deployable decelerators or parachutes.

EDL Trajectory for Blunt-Body Lander Concept

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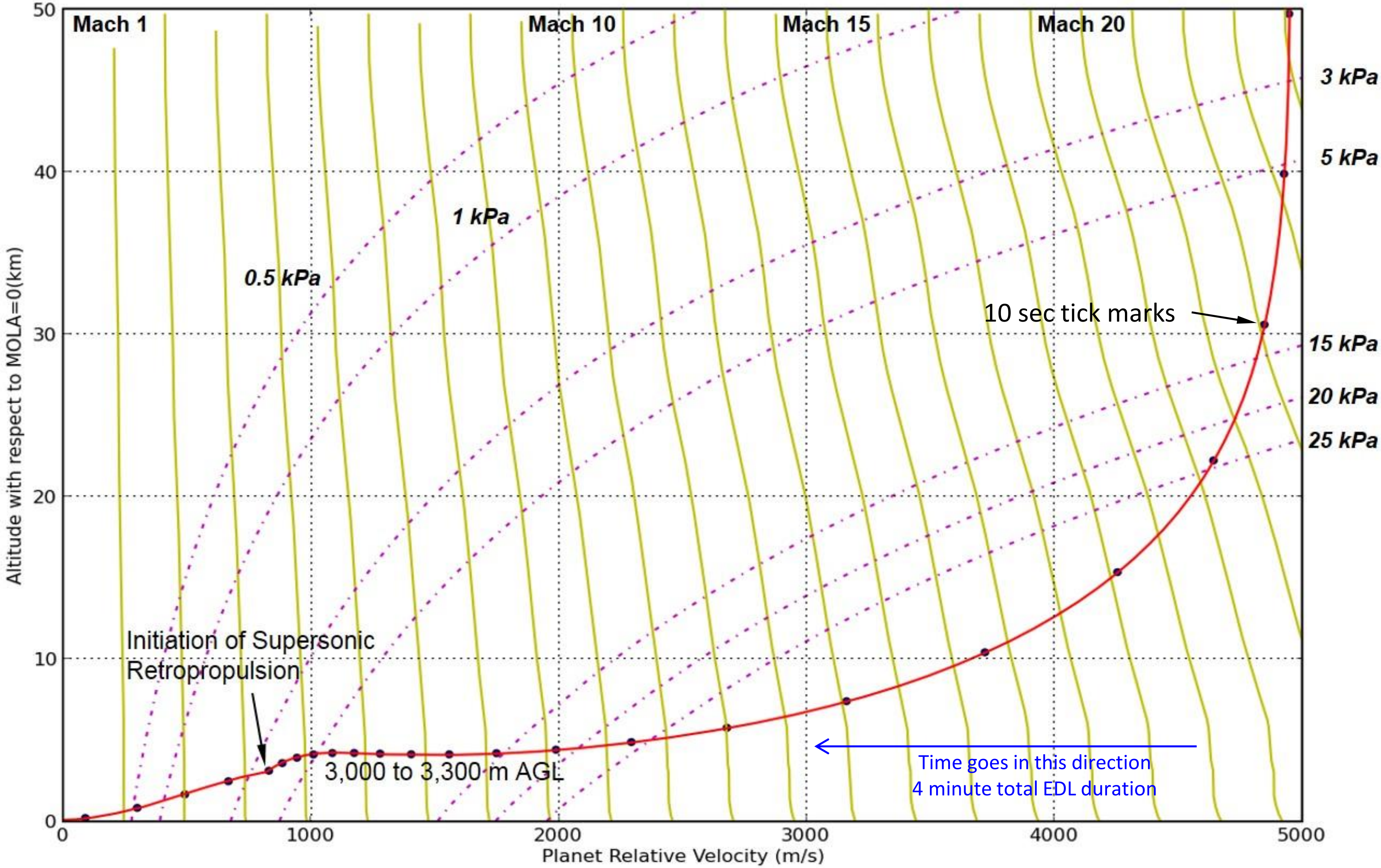

Selected EDL Monte Carlo Results

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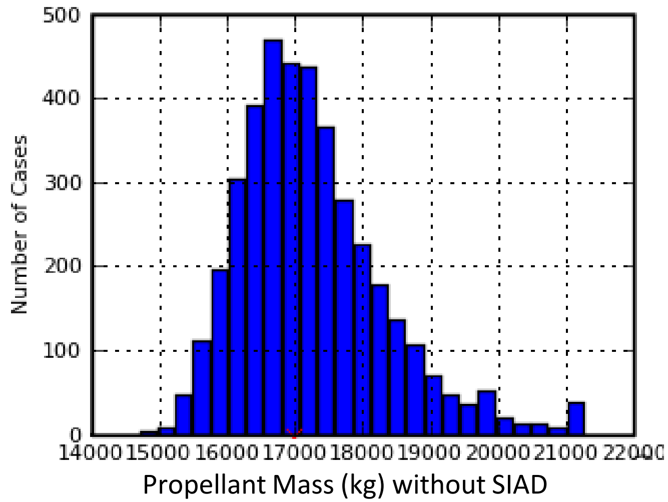
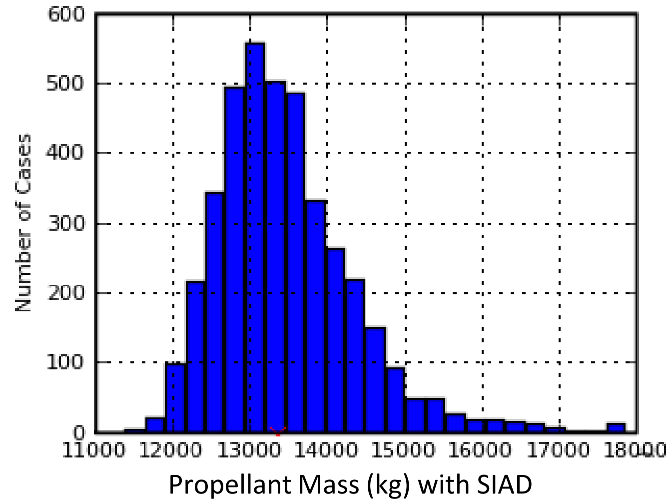
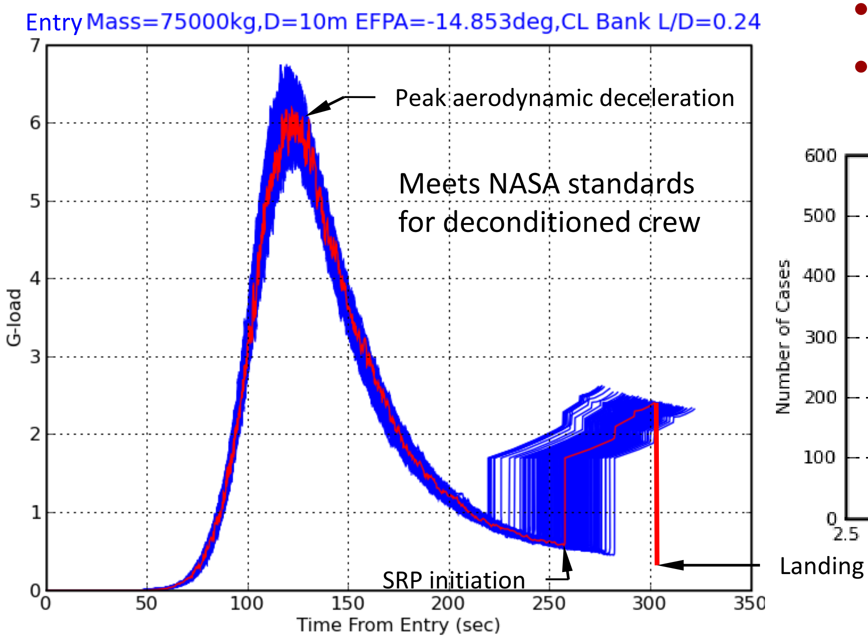
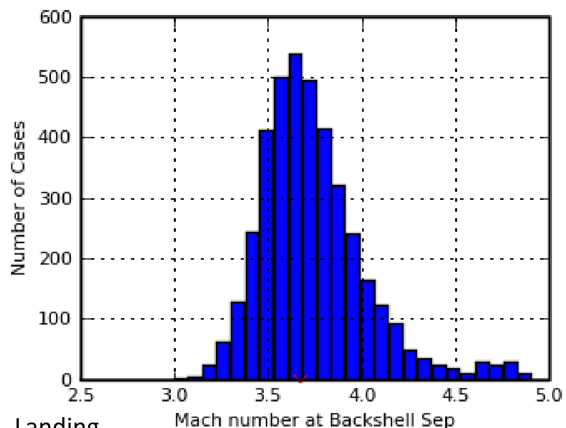
- ~20 t of propellant is used
- Crew experiences ~6.5 g
- Backshell separation and SRP is at ~Mach 3.8 and 4 kPa

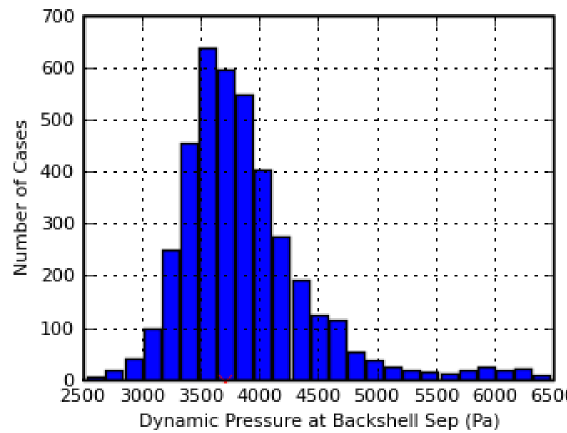




- LDSD derived SIAD could save ~4 t of propellant
- Could be an option for cargo vehicles







One-Year Surface Mission

8 SLS Launches

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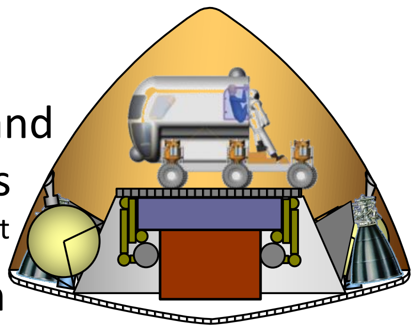
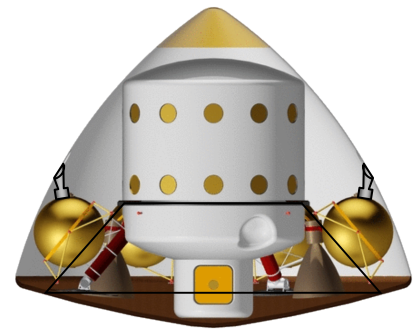
- Would build on the short-stay architecture by adding a surface habitat
  - A cargo lander would carry the surface habitat
  - Crew lander with MAV would carry a crew of 4 to the surface
  - Re-use pressurized rover and other equipment from first mission

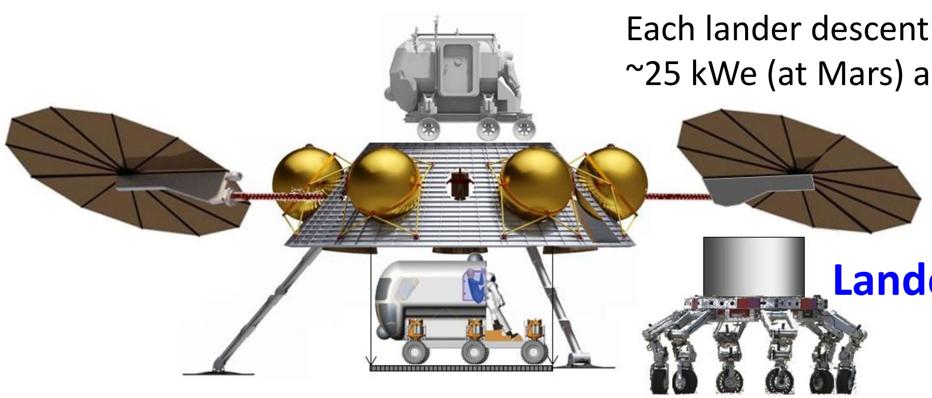
Cargo and logistics from 1st mission



Entry Configurations

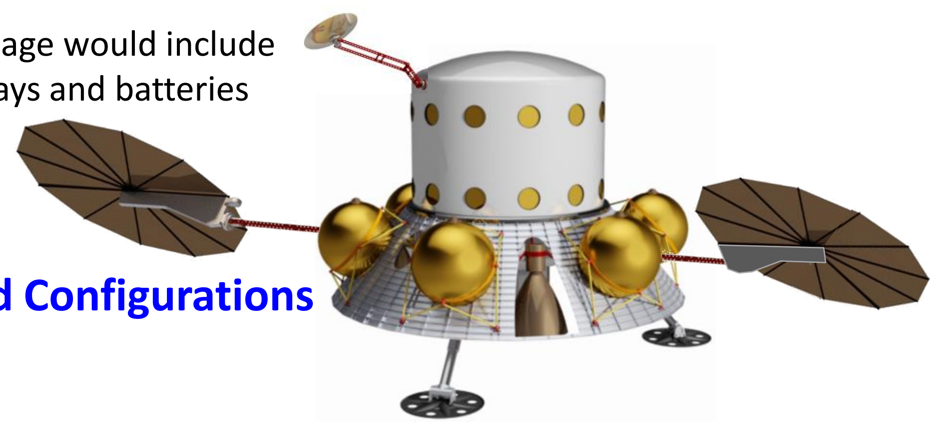


Surface habitat



Each lander descent stage would include ~25 kWe (at Mars) arrays and batteries

Landed Configurations



Long-Stay Mars Surface Mission Concept

1 year surface stay; crew of 4; 8 SLS launches

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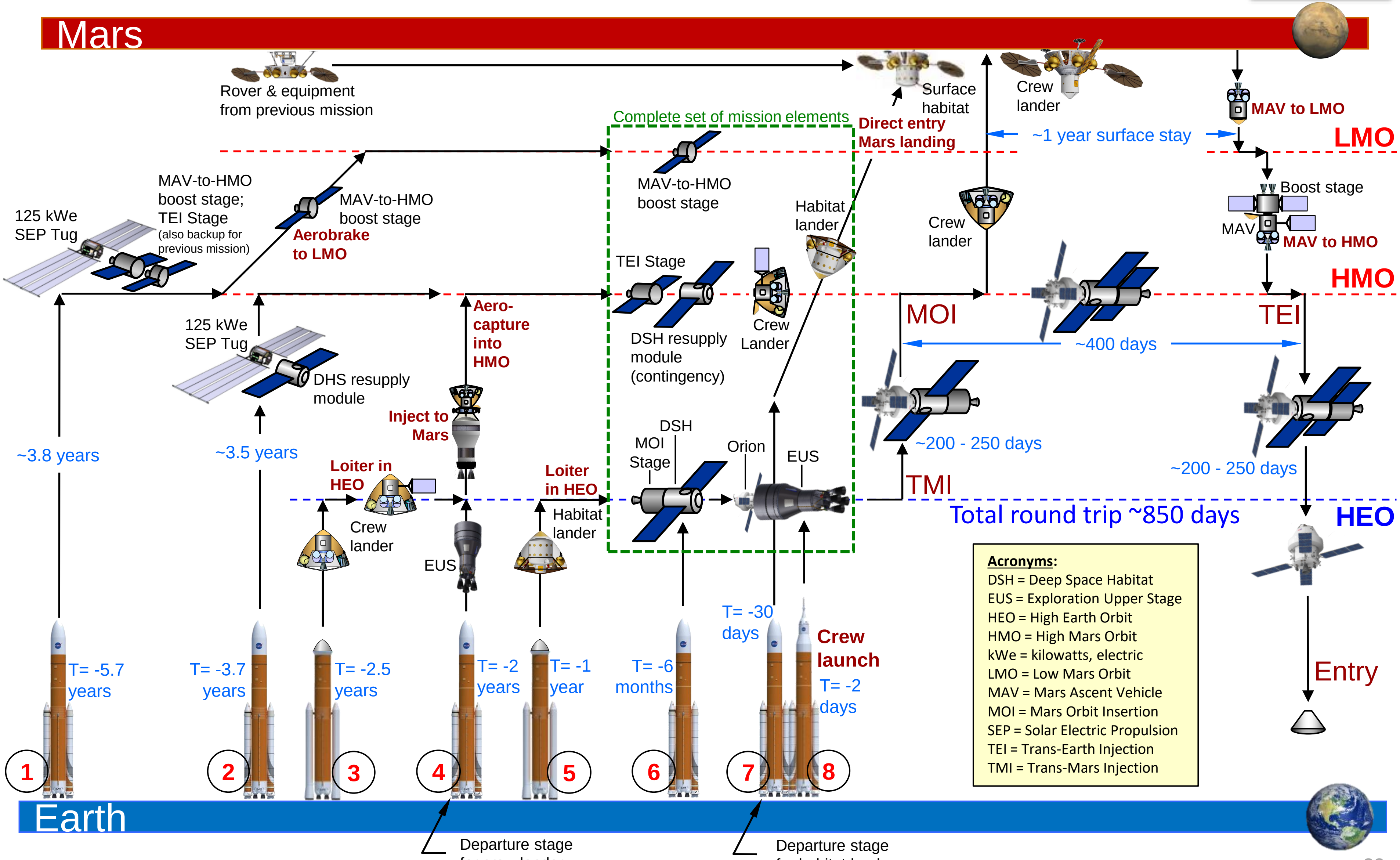

Acronyms:
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kWe = kilowatts, electric
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SEP = Solar Electric Propulsion
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Reusability Concept (1 of 3)

SEP tug retrieves Deep Space Hab at Earth flyby

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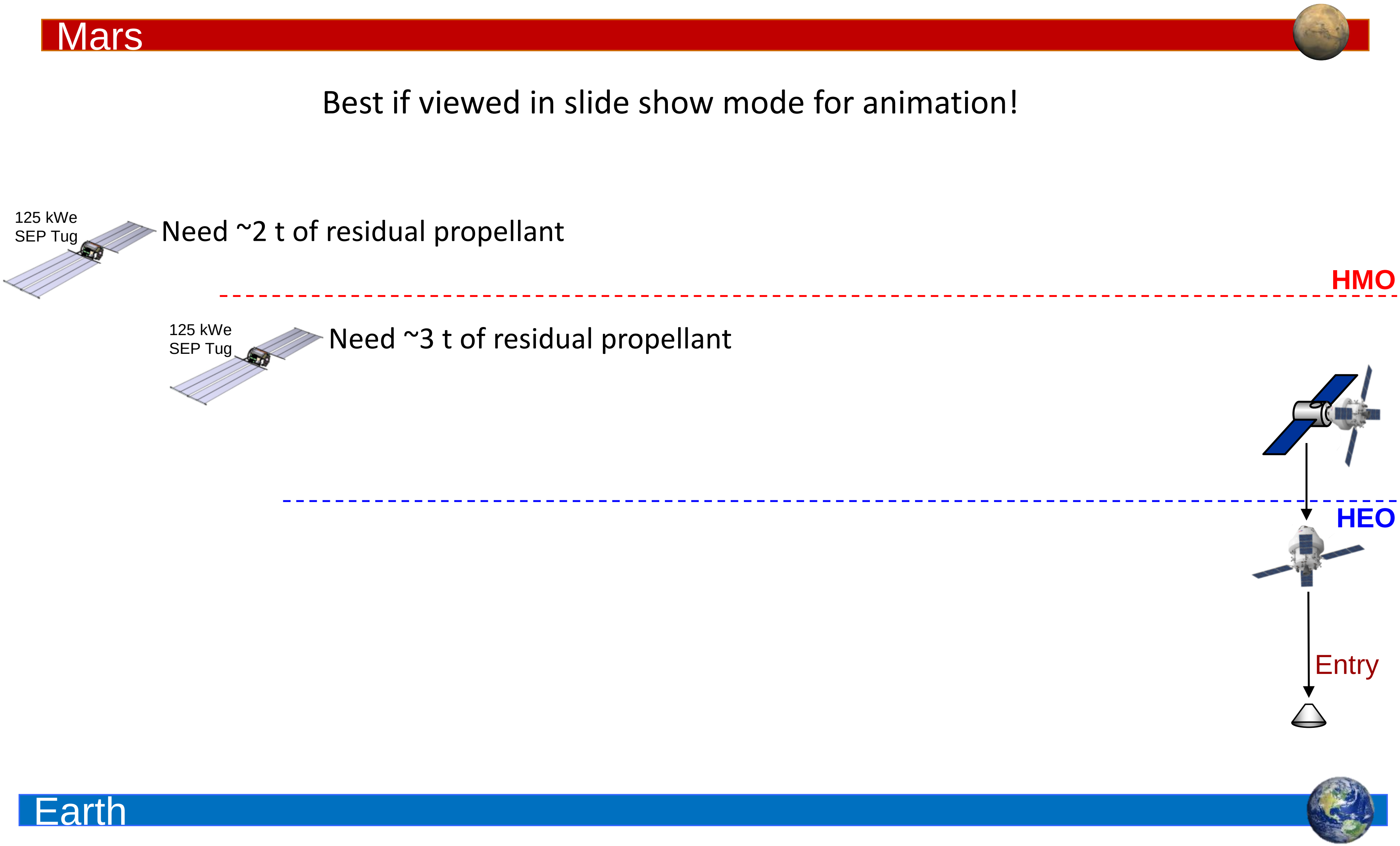

Reusability Concept (2 of 3)

SEP tugs return Deep Space Hab to Deep Space Gateway

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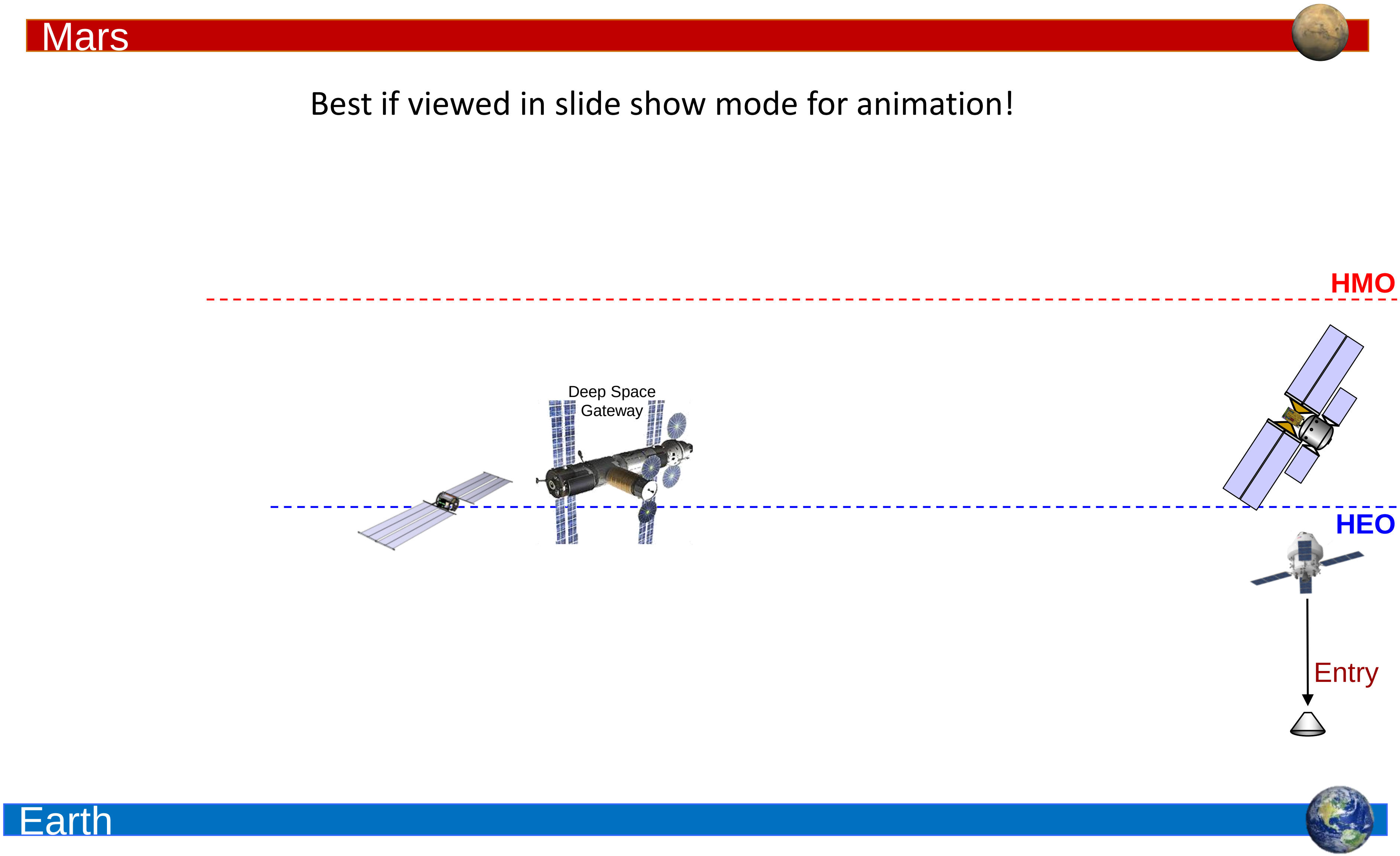
Best if viewed in slide show mode for animation!



Reusability Concept (3 of 3)

Alternate option to return Deep Space Hab to Low Earth Orbit for crew training with commercial crew access

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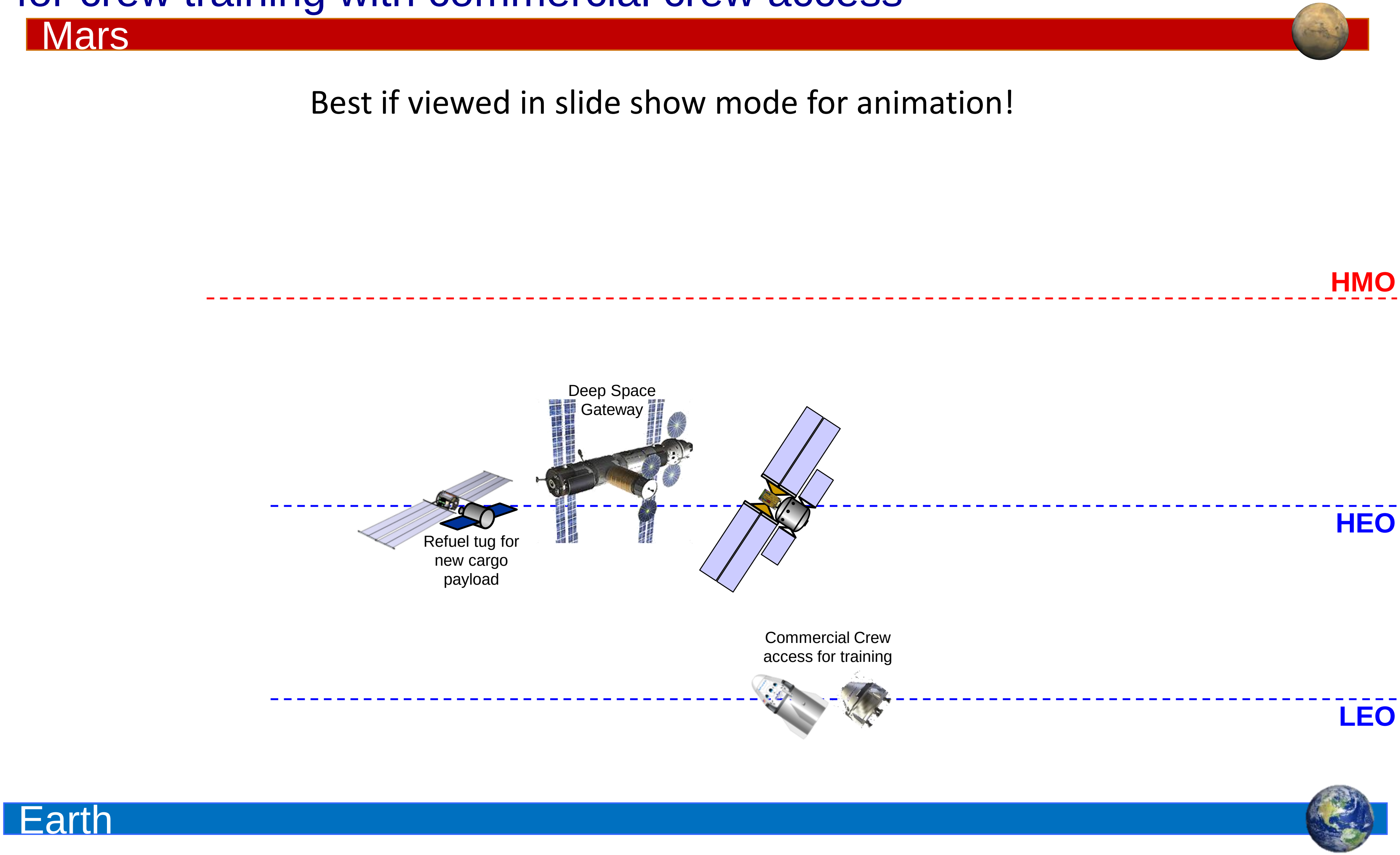
Best if viewed in slide show mode for animation!



Solar Electric Propulsion (SEP) Tug Concept

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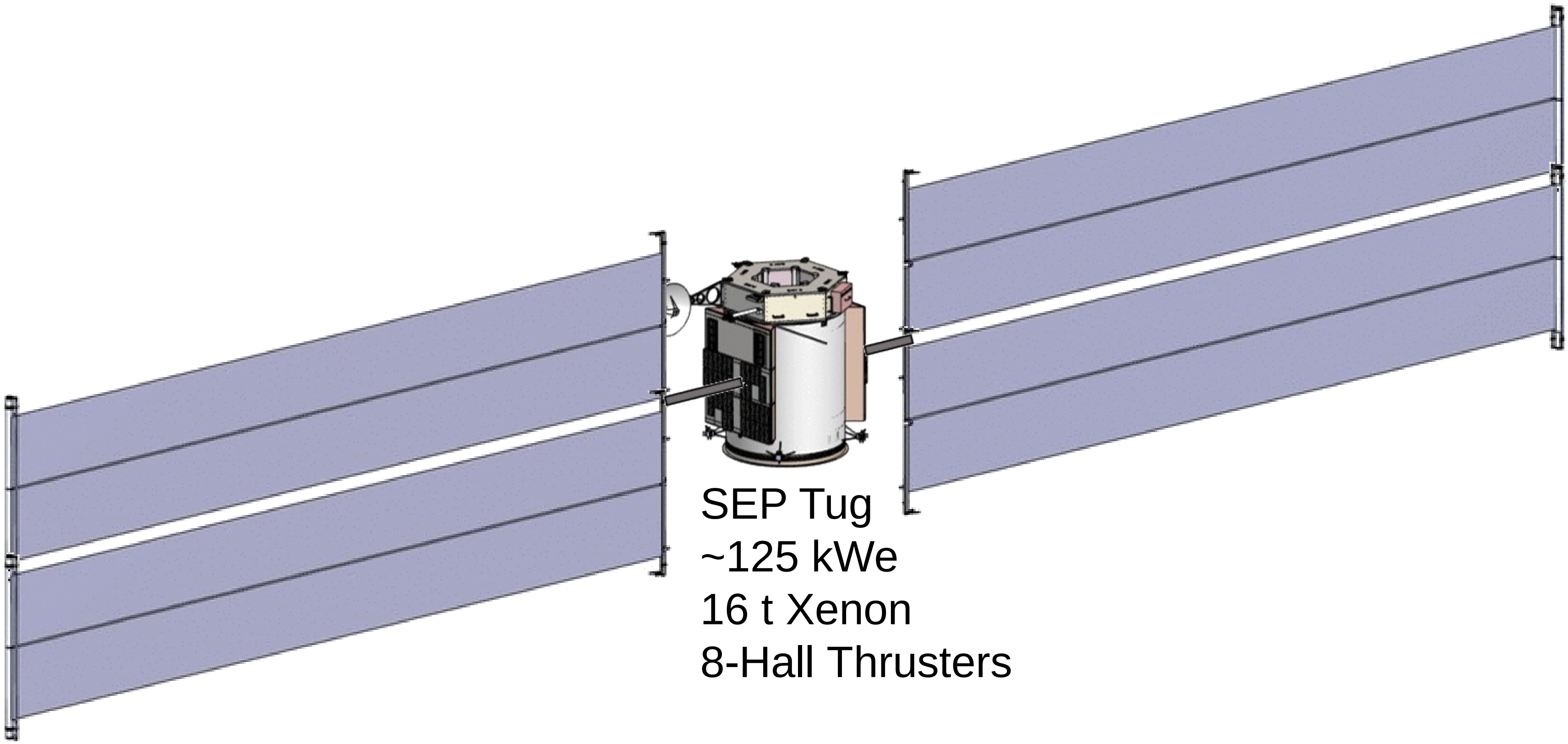

SEP Tug
~125 kWe
16 t Xenon
8-Hall Thrusters

Deep Space Habitat (DSH) Concept

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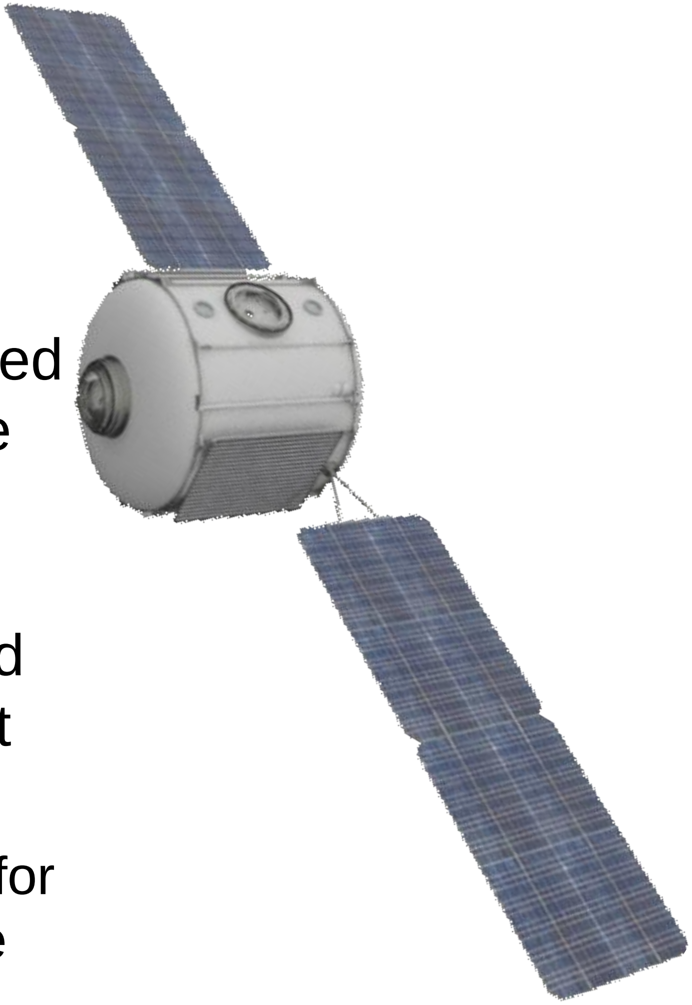
- Could support a crew of 4 for 600 days (transit to Mars and back)
- Mass is approximately 30 t.
- Uses solar arrays and batteries for power
- Attitude control would be provided by an attached propulsion stage or by Orion (depending on mission phase)
- Resupply version would be used to restock the DSH in Mars orbit for long-stay missions
  - Needed only as a contingency for abort to orbit from Mars surface



In-Space Chemical Propulsion Stage (CPS) Concept

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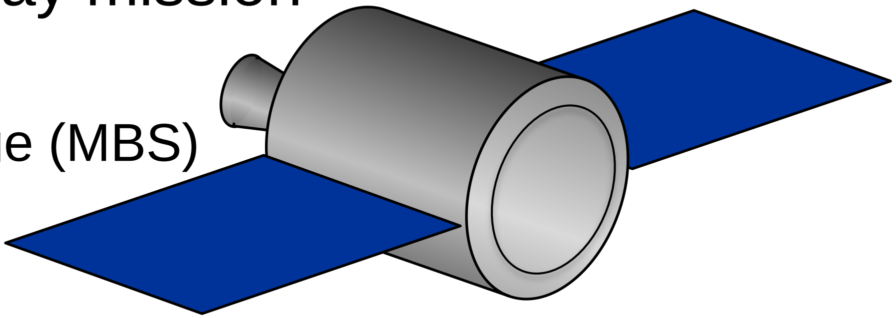
- Would need 4 units for short stay mission
  - 1 for Mars Orbit Insertion (MOI)
  - 1 short stage for MAV Boost Stage (MBS)
  - 2 for Trans-Earth Injection (TEI)
    for the 2033 short-stay mission.
    (Note: only 1 TEI stage needed for long-stay missions)



- MMH/NTO biprop stage with a pump-fed engine; similar in size to the Titan II second stage or Proton 3rd stage
  - Could use existing design RS-72 engines
  - Would have solar arrays and avionics for independent operation

Crewed Mars Lander Concept

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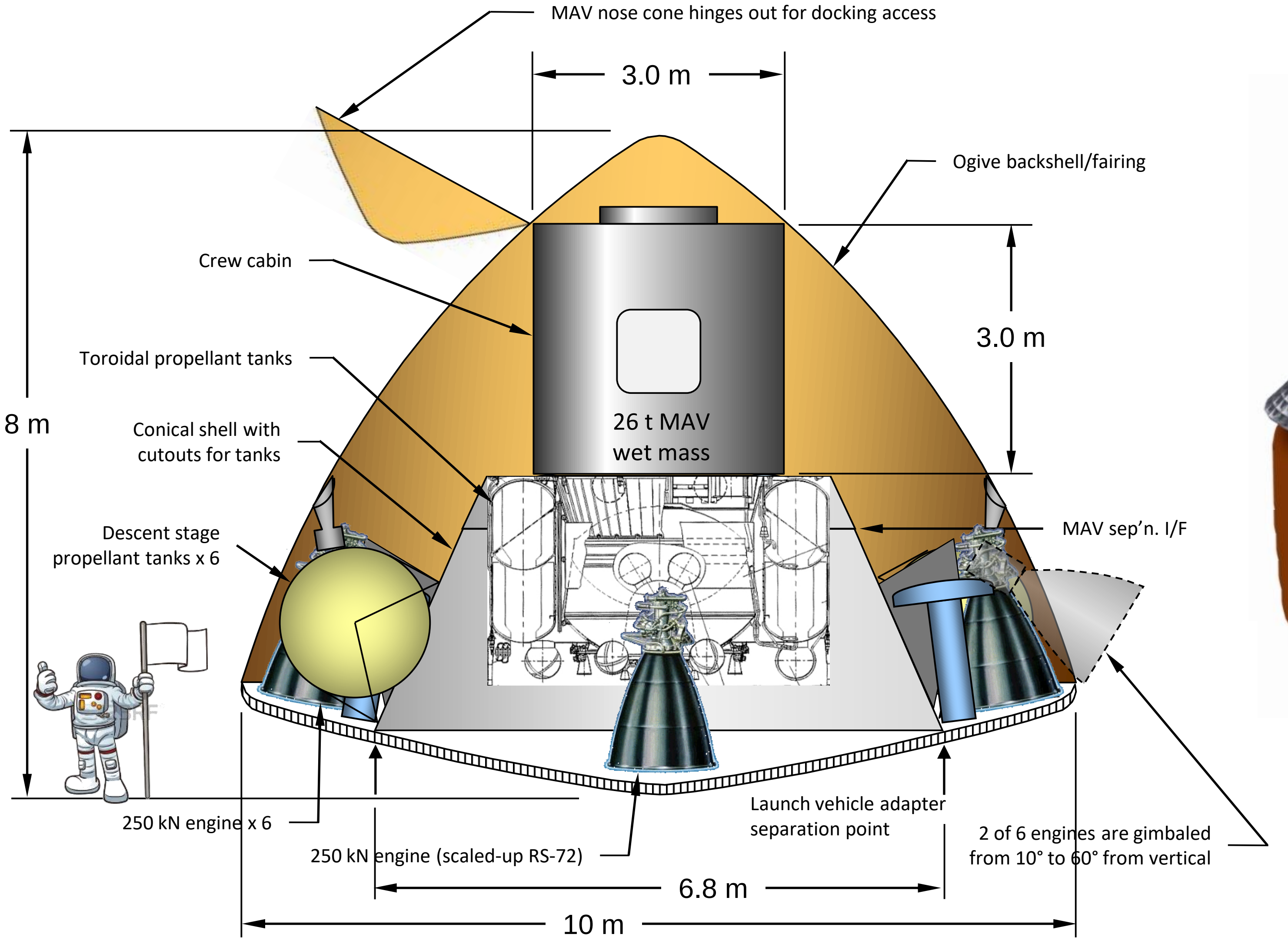

MAV in flight

Features of Example MAV Design

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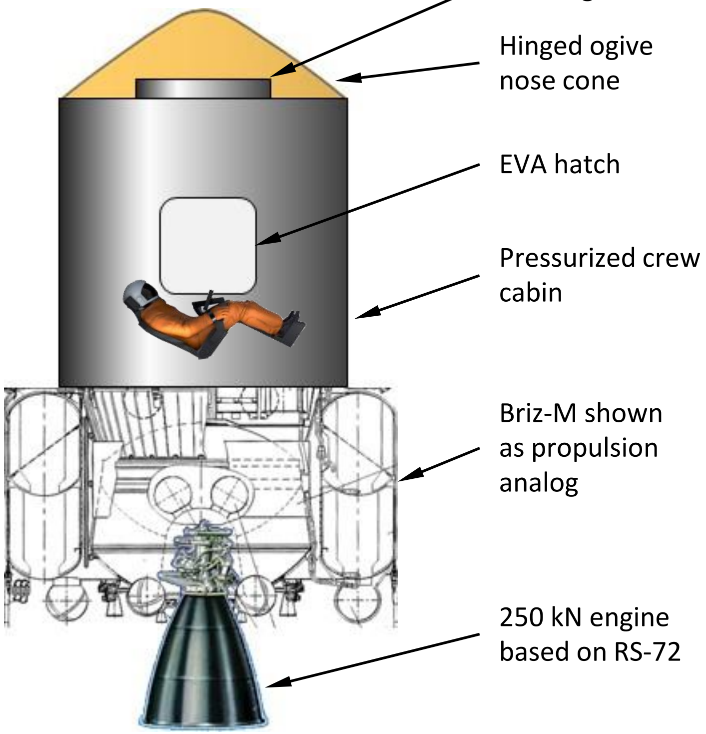
- Simple single-stage non-cryo high-heritage biprop system (MMH/MON-15)
  - Briz-M stage was used as an analog for mass and propellant capacity
  - Briz-M can stage the outer toroidal tanks, but that benefit was not used here
  - Single pump-fed engine (example is sized at 250 kN)
- Fully fueled to allow for abort capability during EDL and after landing, providing for return to orbit without requiring interaction with any Mars surface infrastructure
- Ascent would be to Low Mars Orbit (LMO)
  - Would dock with boost stage in LMO to return to High Mars Orbit (HMO)
- Moldline concept is aerodynamic
  - Hinged nosecone would protect docking system from dust and debris
- Concept is to be able to support a crew of 4 by itself for 7 days, and longer with other surface assets (e.g. press. rover and/or habitat)
  - Seating would be reclined and on one level
- No airlock: egress/ingress Apollo LEM style
  - Alternately could use transfer tunnel



Mars Cargo Logistics Lander Concept

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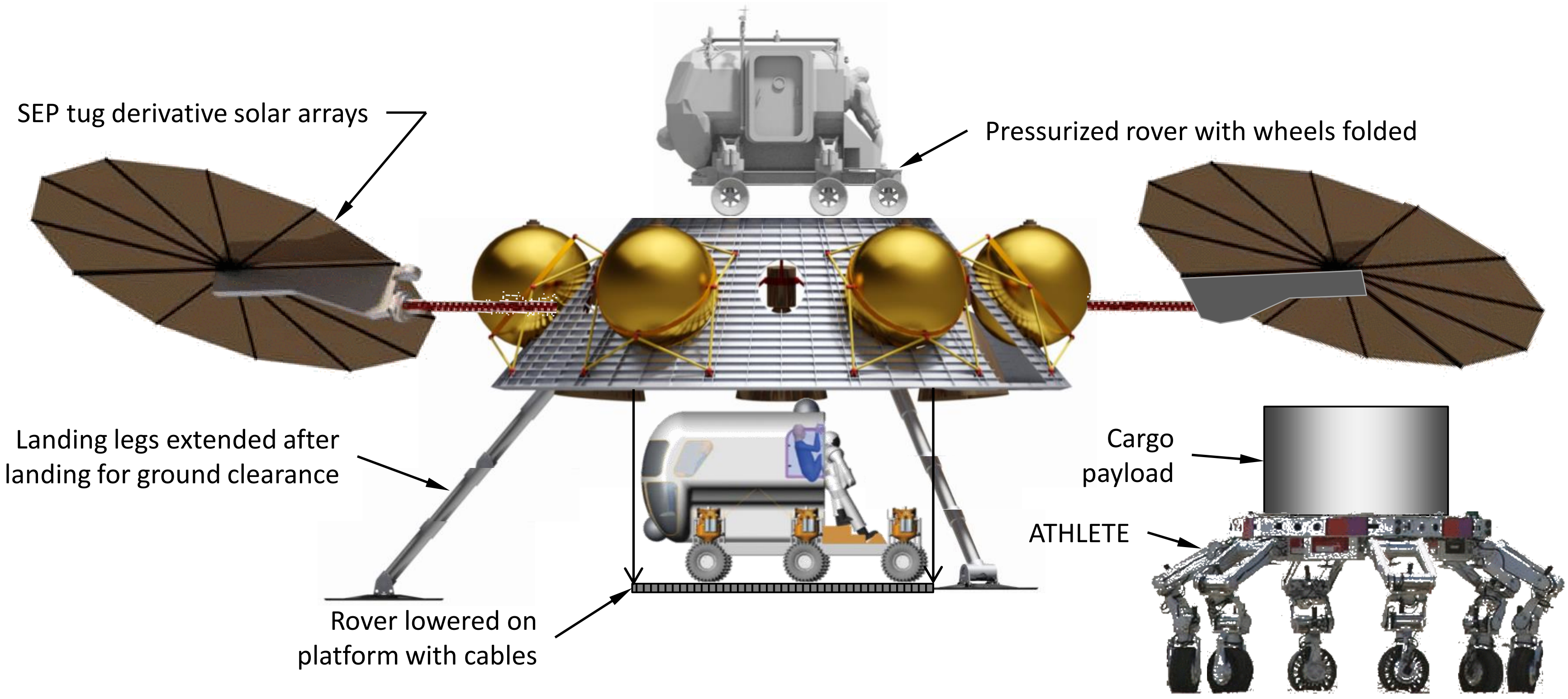

Concept for Descent/Ascent Vehicle (DAV) Transit to High Mars Orbit

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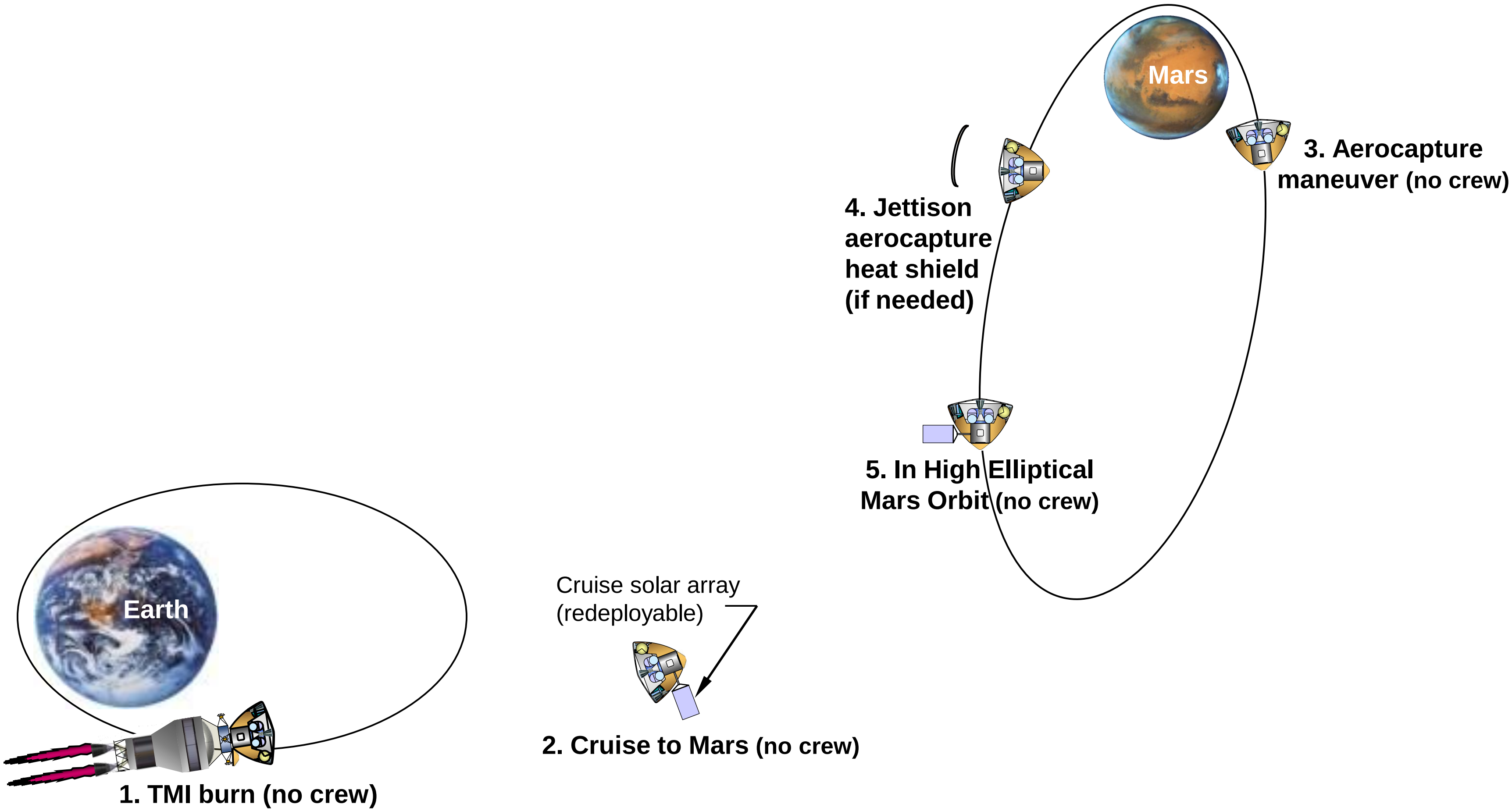

Crewed Mars Descent/Ascent Vehicle Concept

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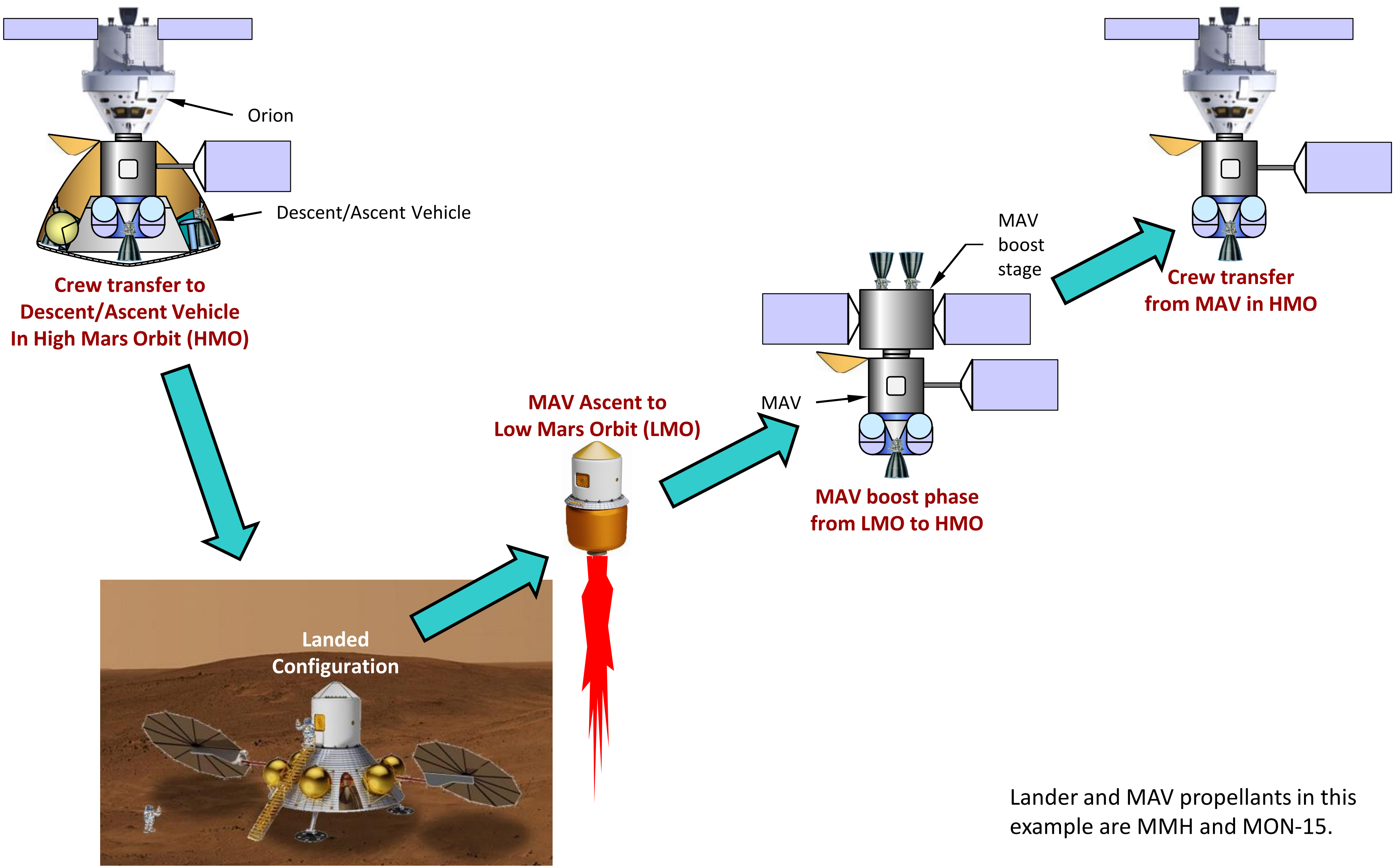

Lander and MAV propellants in this example are MMH and MON-15.

Concept for MAV Ascent, Transfer to Deep Space Hab, and Preparation for Trans-Earth Injection

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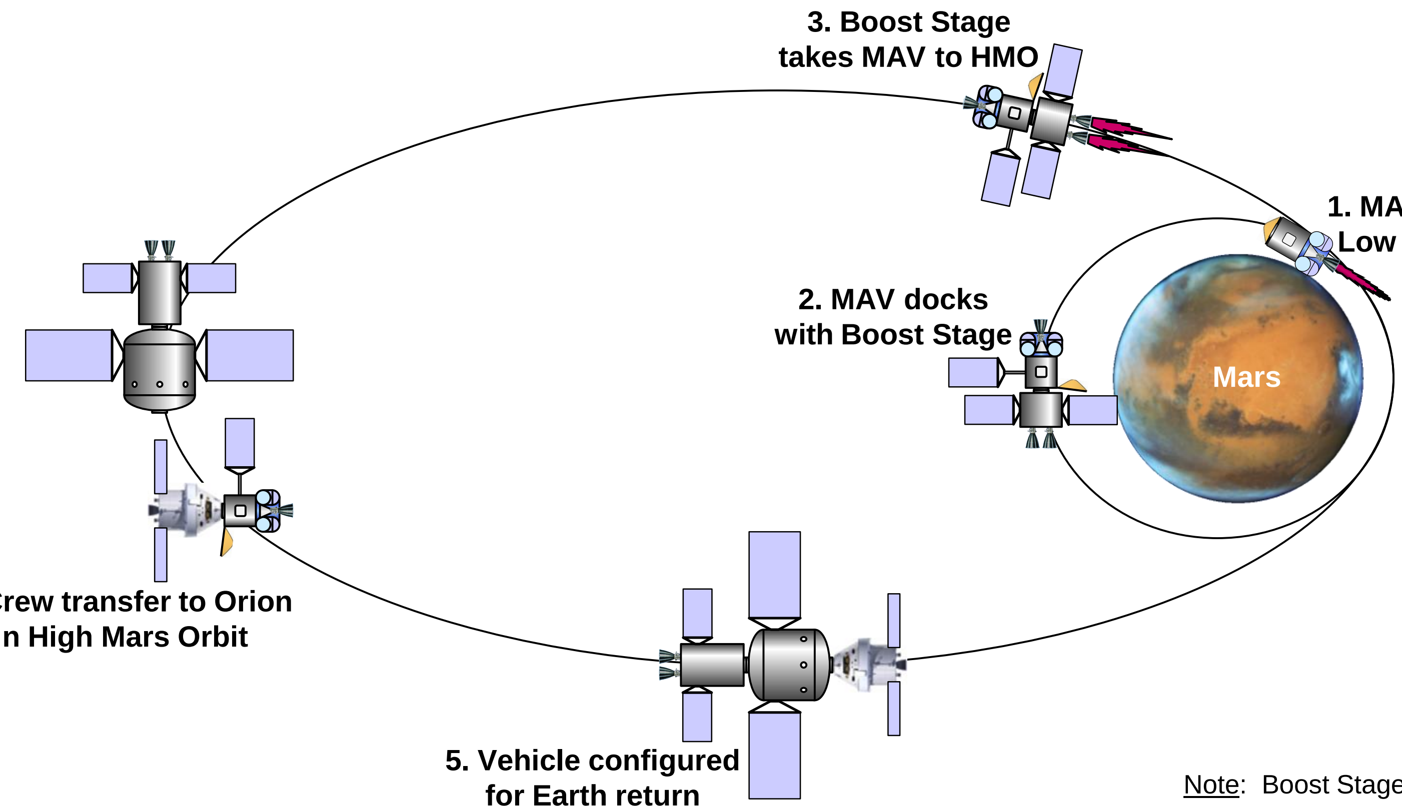

Note: Boost Stage was previously delivered by SEP cargo flight to HMO and aerobraked down to LMO.

SLS Block 2 Launch Concepts for Minimal Architecture

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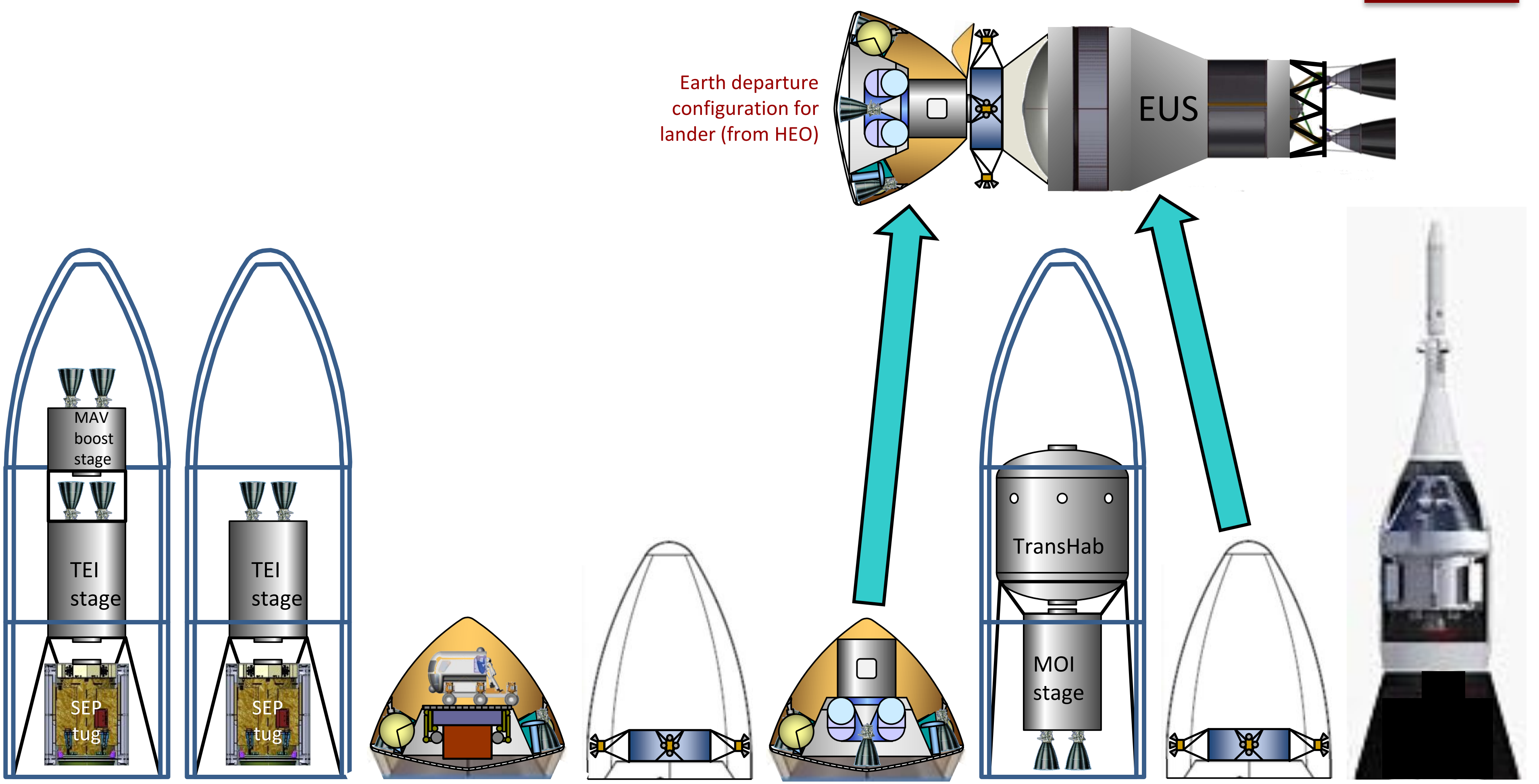

TEI 1 and MAV boost stage cargo launch	TEI stage 2 cargo launch	Cargo lander to HEO using back-shell as payload fairing	Docking kit for EUS to use as departure stage	Crew lander to HEO using back-shell as payload fairing	MOI stage and TransHab launch to HEO	Docking kit for EUS to use as departure stage	Orion with crew
Launch #1	Launch #2	Launch #3	Launch #4	Launch #5	Launch #6	Launch #7	Launch #8

Launches #4, #7, and #8 have limited launch periods. The other launches have flexible launch dates.

Notional Crewed Mars Transit Vehicle Configurations

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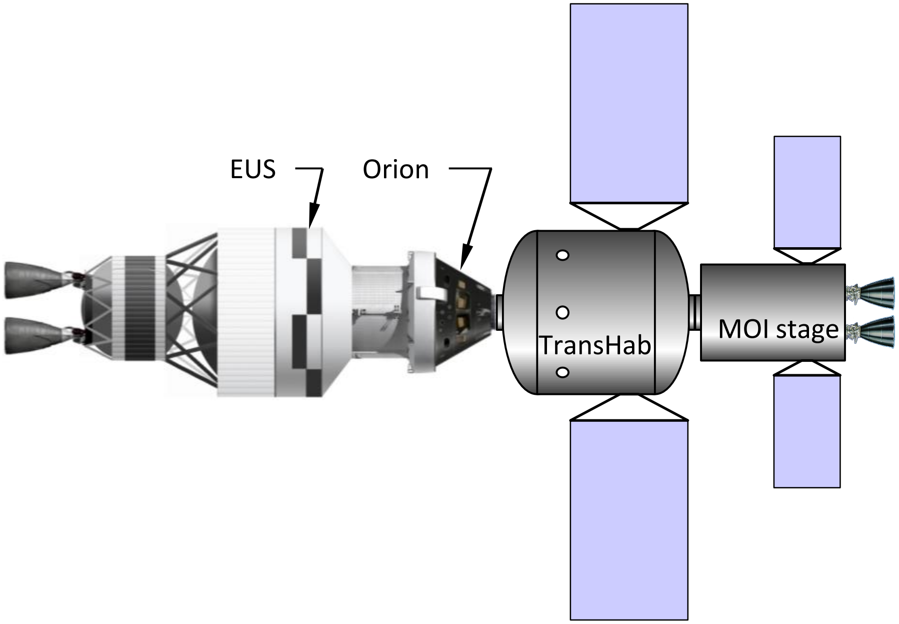
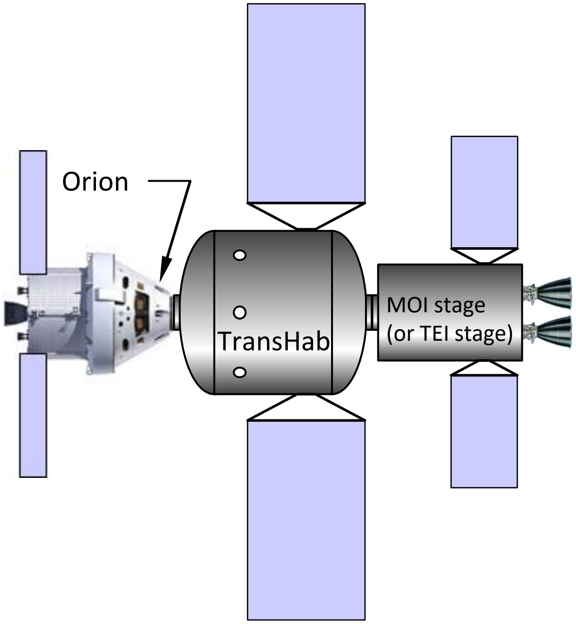


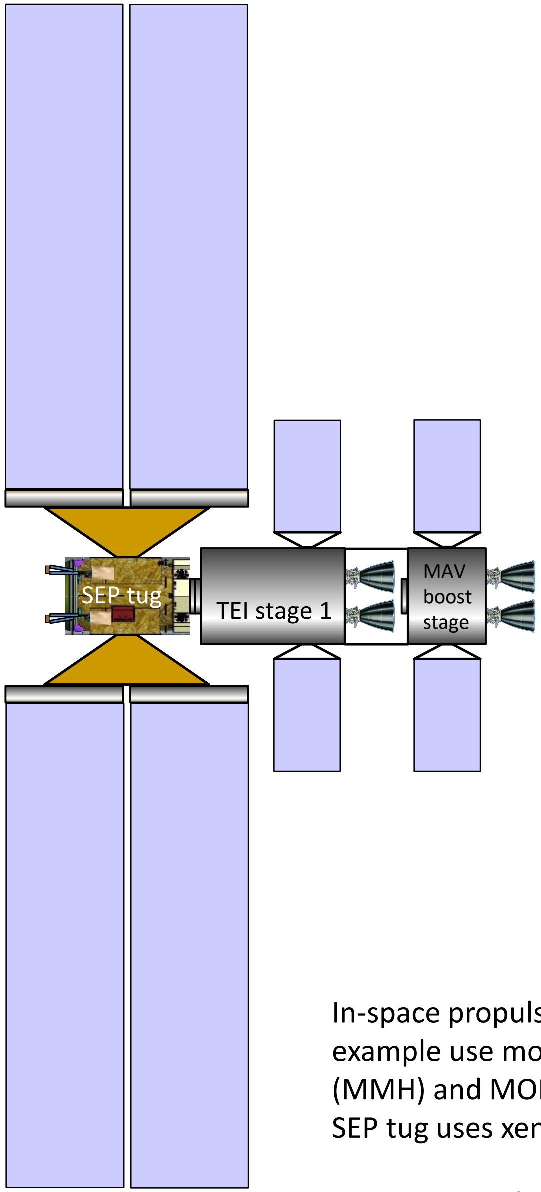
Earth departure configuration for crew

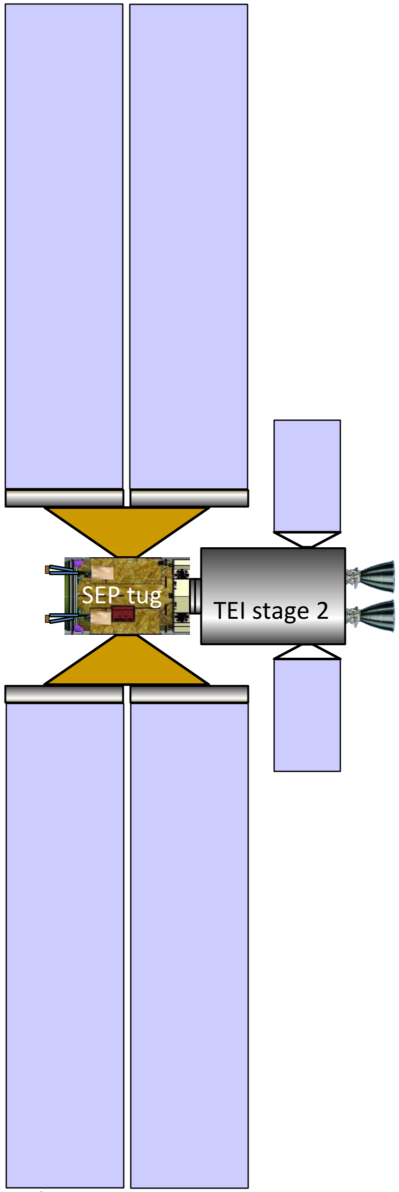


Earth/Mars transit configuration

Notional SEP Tug Cargo Flight Configurations

H2M
Minimal Architecture





In-space propulsion stages in this example use mono-methyl hydrazine (MMH) and MON-15 propellants. SEP tug uses xenon propellant.

Contingency and Abort Capabilities

H2M
Minimal Architecture

- MAV concept would have abort-to-orbit capability during EDL and after landing
- For long-stay missions, the TEI stage for mission N+1 would arrive in HMO in time to serve as a backup for mission N
  - The MAV boost stage for mission N+1 might also arrive in time to be a backup for mission N, but the timing is close
- For long-stay missions, there is the potential for the DSH resupply vehicle be upgraded to a full DSH to serve as a backup for Earth return
- Orion could function as a temporary lifeboat in the event of other vehicle anomalies
- Orion could provide emergency EVA capability

Opportunities for Commercial Services in Minimal Architecture Example

H2M
Minimal Architecture

- Crew and cargo missions to low Earth orbit
  - ISS crew and cargo deliveries for LEO testing of Mars systems
  - Regular crew training flights to LEO throughout the course of the program to provide a steady and ample supply of astronauts trained and qualified for Mars missions
- Cargo deliveries to the Deep Space Gateway (DSG)
- Privately funded lunar missions that could be staged from the DSG
- Cargo deliveries to the Martian surface
  - To supplement the large cargo landers launched by SLS